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RD&E CENTER

Technical Report

No. 13129

LIGHTWEIGHT MBT TRACK PIN DEVELOPMENT

CONTRACT DAAE07-83-C-R075

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Approved for Public Release,
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An 18 month program was conducted by DWA Composite Specialties, Inc., for the U.S. ~~United States~~ Army Tank-Automotive Command Research and Development Center, Warren, Michigan, for "Light-Weight MBT (Main Battle Tank) Track Pin Development." The track pin is composed of a DWA1 20® liner installed by interferences (shrink) fit into an outer steel casing.

DWA1 20® is a metal matrix composite incorporating aluminum powder and ceramic particulate reinforcement. The DWA1 20® system selected for the track pin application is 25 volume percent silicon carbide particulate reinforced 6061 aluminum (25v/o SiCp/6061); however, other combinations are feasible.

Commencing with DAW1 20® billets, tubes were extruded, then cut to size and machined for shrink-fit assembly into the pre-sized H-13 steel tube casings. The steel was heat-treated prior to insertion. The hybird pin was subsequently subjected to DWA1 20® heat-treat parameters, followed by end-configuration machining.

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FOREWORD

This document is the final report to the United States Army Tank-Automotive Command Research and Development Center Contract DAAE07-83-C-R075 for "Lightweight MBT Track Pin Development."

The program was conducted by DWA Composite Specialties, Inc., Chatsworth, California from July 1983 through January 1985, under the sponsorship of U.S. TACOM, Warren, Michigan. Mr. Mike Holly and Mr. Don Ostberg served as the Army technical representatives.

Development of the lightweight hybrid track pin was based on the following design criteria:

- o interchangeability with the present steel track pin;
- o sufficient strength with significant weight saving.

The DWA concept involves shrink-fit assembly of a DWAl 20® sleeve into a high strength steel casing.

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1.0. INTRODUCTION

This final technical report, prepared by DWA Composite Specialties, Inc. for the U.S. Army Tank-Automotive Command under Contract DAAE07-82-R075, describes development and testing conducted to establish a mass production technique for lightweight tank track pins. The methodology herein adapted to track pin fabrication is based on proven interference-fit technology. The new, lightweight pin is designed to replace and be interchangeable with TACOM Part No. 12274418, with a weight savings approaching 30 percent. Because of the sizeable quantity of track pins involved in each tank system, the expected weight reduction holds promise to contribute significantly to tank performance.

The basic approach selected by DWA to produce lightweight track pins of adequate strength is to combine steel outer jackets with DWAl 20® metal matrix composite inner sleeve extrusions. The steel jacket and DWAl sleeve are so designed that by heating the steel and/or chilling the DWAl, the sleeve may be inserted into the jacket by a high-speed hydraulic ram. Upon temperature stabilization, the hybrid track pin shrink-fit assembly is accomplished.

Summarizing the final lightweight pin design, the outside envelope is interchangeable with TACOM Part No. 12274418. The outer casing is H-13 steel with a 0.162 inch wall thickness. An inner sleeve is incorporated which is constructed of DWAl 20® extruded tube, 25v/o SiCp/6061 metal matrix composite.

The weight of the lightweight hybrid track pin is 27 percent less than the present alloy steel unit.

2.0. OBJECTIVES

The primary purpose of this contract was to establish a mass production technique for lightweight track pins. Processes used had to be proven in research and development and had to include methods that could be expanded for mass production of quantities up to 500,000 track pins per year.

Further objectives included selecting materials with goals of longitudinal tensile strength of 140 ksi, longitudinal modulus of elasticity of 20×10^6 psi, minimum yield strength of 85 ksi, and weight savings of 30 percent over the alloy steel used in track pin applications at the time of this contract.

Finally, the new lightweight pin had to withstand fatigue loading under repeated stress cycling with a goal of 150 ksi maximum and 2.05 ksi minimum stresses, for 2,000,000 cycles, and to be further capable of withstanding 11,000 pounds static force in three-point bending on a 19 inch center.

3.0. CONCLUSIONS

The use of DWAl 20® in constructing tank track pins provides a practical method of replacing heavy steel with lightweight aluminum matrix composites

without an unacceptable strength loss. The interference shrink-fit assembly method further provides a potential means for mass production at a reasonable cost.

Additional research may further reduce the weight of the hybrid track pin by switching to a lower density reinforcement and increasing the volume fraction of the inner sleeve.

In the following table, the track pin physical properties obtained are compared with program goals.

	Goal	Obtained
Ultimate Tensile Strength	140 ksi	181 ksi
Yield Tensile Strength	85 ksi	155 ksi
Modulus of Elasticity	20×10^6 psi	27×10^6 psi
Weight Saving	30 percent	27 percent

The above values were calculated using component physical properties. To evaluate actual pin values and to assess the achieved proximity to static bending and dynamic fatigue goals, tests were conducted on final pin configurations with the following results:

- Bending Strength - The pin sustained an 11,000 pound force applied in three-point bending between supports spread 19 inches apart. A permanent set of only 0.030 inches was measured.

- Fatigue Strength - The pin fatigue test was conducted by repeatedly applying a load in three-point bending centered between supports spread 19 inches apart. The fatigue level obtained averaged 107,000 cycles. The applied load was equivalent to 150 ksi peak bending stress.

  During the track pin development effort, major emphasis was placed on weight reduction, static strength, and stiffness. These objectives were exceeded; however, the resulting design was lower than expected in fatigue resistance. Selecting one of the other candidate steels for the pin casing, while not as desirable to meet static strength and stiffness goals, could have permitted a higher fatigue level to be achieved.

4.0. RECOMMENDATIONS

The following recommendations are based on experience gained during developing the lightweight track pin and the pin insertion assembly (P.I.A.) apparatus.

- Select an outer casing steel that exhibits better fatigue strength subsequent to heat up and insertion.

- Conduct research to more fully optimize the DWAl sleeve Metal-Matrix Composite (MMC) system and pin configuration for maximum strength-to-weight at the required strength level.

- Improve the oven subsystem of the pin insertion assembly apparatus, and refine the interference fit sequence.

- Study the sequences of pin assembly and heat treatment to improve subsequent mechanical performance, evaluate the feasibility of reducing pin insertion temperature, and heat treat the DWAl sleeves before inserting the assembly.

- Investigate selecting higher strength and stiffness DWAl sleeve material, e.g., 7090 Al, 2124 Al, and higher reinforcement loading.

- Demonstrate mass production of hybrid pins via Man Tech funding to fabricate several thousand items.

5.0. TECHNICAL DISCUSSION

The mass production technique described herein for the DWAl 20® steel hybrid lightweight track pin involves shrink-fit of concentric tubular parts such as a high strength steel jacket encasing a metal matrix composite inner sleeve.

The key to the hybrid pin fabrication method is the hydraulic shrink-fit pin insertion assembly apparatus shown in Figure 5-1. Material selection results met the goals of lightweight and high strength in the pin illustrated in Figure 5-2, which was assembled by shrink-fit insertion, then machined on the ends as required.

5.1. Background

This contract is part of an overall effort to investigate means to reduce the operational weight of the MBT system. The DWA approach to pin weight reduction is to replace a significant portion of the present steel material with aluminum metal matrix composition. The resulting lightweight track pin production process capability is based on the requirement of 500,000 track pins per year.

The DWA metal-matrix composite DWAL 20® used in the pin sleeve is a ceramic-particulate reinforced MMC which can be essentially tailored to meet specific system requirements by selection of the matrix alloy, and the reinforcement type and level. The structural requirements of flexural strength and weight reduction formed the primary basis for the hybrid track pin DWAl sleeve system choice. A compromise MMC system, 25v/o SiCp/6061, was chosen to provide a reasonable balance of strength and ductility of the inner sleeve, while assuring producibility compatible with the high strength steel casing performance.

5.2. Track Pin Design

Design criteria for developing the lightweight MBT track pins included the following goals:

- Compatibility with mass production, and reasonable cost.

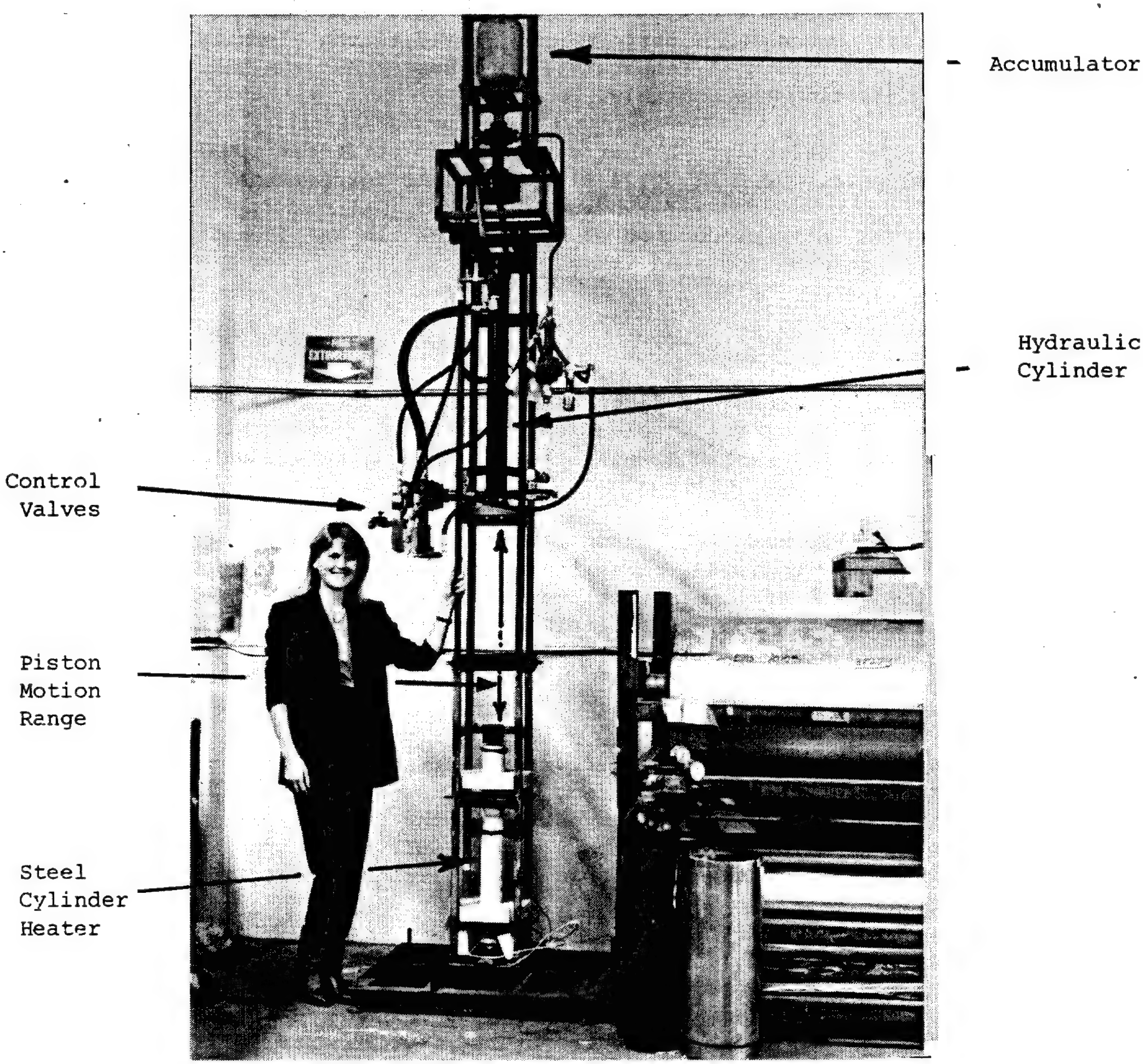


Figure 5-1. Hydraulic Shrink-fit Pin Insertion Assembly Apparatus for the Steel and DWAl 20® Hybrid Track Pin Production

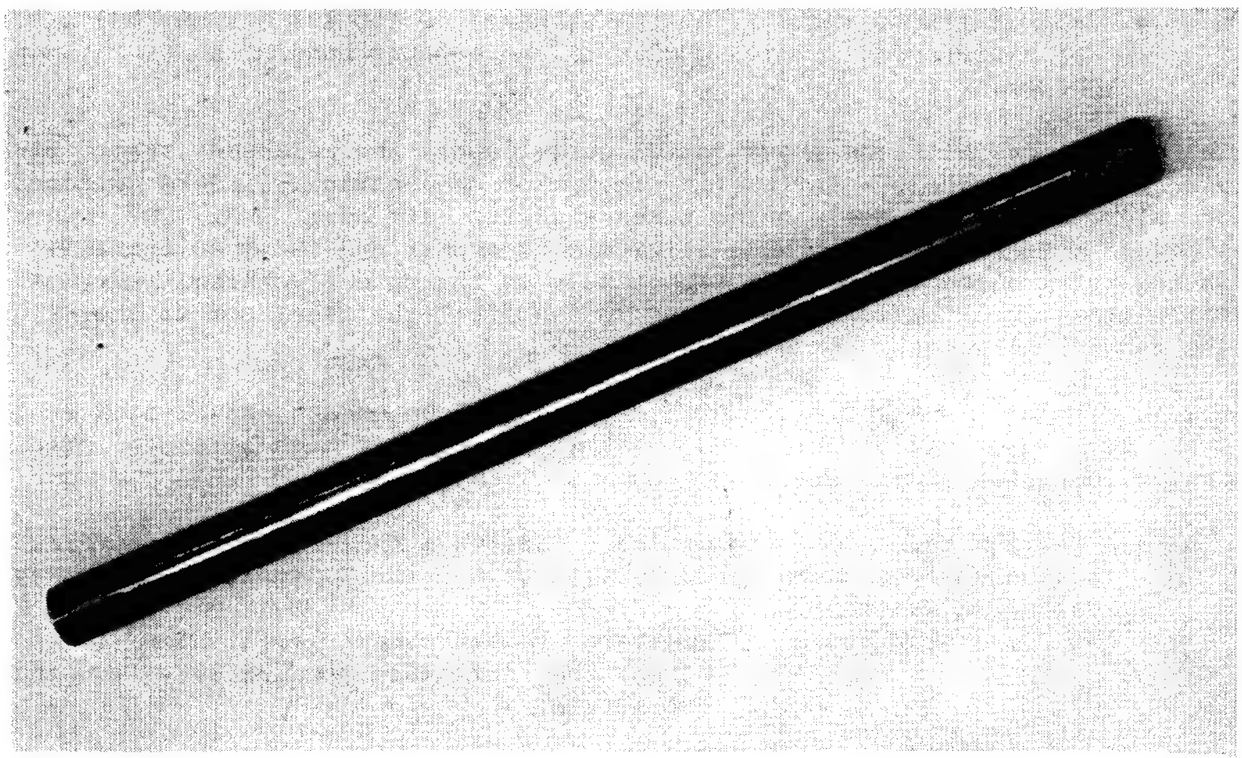


Figure 5-2. Lightweight Track Pin Constructed of DWAl 20® Metal Matrix Composite Encased in a Steel Jacket

- 30 percent reduction in weight.

- Interchangeable with present pin, Army P/N 12274418:
  - chemical compatibility
  - dimensional compatibility

- Structural mechanical property goals:
  - ultimate tensile stress = 140 ksi
  - yield tensile stress = 85 ksi
  - modulus of elasticity = 20×10^6 psi

- Capability to withstand a static load of 11,000 pounds applied in three-point bending on a 19-inch center.

- Capability to sustain fatigue stresses of 150 ksi maximum and 2.05 ksi minimum for 2×10^6 cycles of three-point bending on a 19 inch center.

In consonance with the above design guidelines, the selected track pin assembly approach is a shrink-fit concept of concentric cylinders composed of high strength steel outer tubes encasing extruded DWAl 20® inner sleeves. In this manner, the intrinsic toughness and fatigue characteristics of the steel were used effectively on the outer (working) surface, while the lighter composite was used to "support" the steel and to decrease the hybrid pin weight.

5.2.1. Material Selection. With hybrid pin components established as a DWAl 20® inner sleeve installed by shrink-fit into a high strength steel casing, material final selection began.

- DWAl 20® Mechanical Properties - Candidate DWAl systems were first evaluated from known characteristics, and the following preliminary selection was made:

- 20v/o SiCp/6061:	Moderate reinforcement level, for evaluating the influence of ductility in the hybrid pin.
- 25v/o SiCp/6061:	Higher stiffness system for comparison with the more ductile, similar 20v/o system. Most DWA extrusion experience. Excellent environmental and handling characteristics. Moderate ductility DWAl alloy. Moderate mechanical properties. Low cost raw material.
- 25v/o SiCp/7090:	Strongest DWAl 20® matrix alloy. Moderate extrusion experience. Low cost raw material. High strength 7000 series PM matrix alloy for direct comparison with the 6000 series matrix. Same higher reinforcement level.

- 25v/o SiCp/2124: Favorable ductility DWAl alloy. Moderate extrusion experience. Moderate strength system. Low cost raw material.

- 35v/o B_4C/Mg Alloy: A minimized-weight DWAl 20® system for preliminary evaluation of the lightest weight track pin option.

Mechanical properties of the aluminum matrix candidate systems are presented in Table 5-1. Based on analytical evaluation, the mechanical properties shown, previous extrusion and other fabrication experience, the selection was narrowed to a reinforcement level of 25v/o SiCp with the matrix alloys 6061 and 7090.

- High-Strength Steel Properties - Criteria for selecting steel casing material included:
  - high yield strength;
  - tempering characteristics to maintain strength after shrink-fit and compatible with DWAl sleeve post-insertion heat treatment;
  - availability.

  Candidate steels are described in Table 5-2. Most acceptable steel tubing required mill runs of tube extrusions including the selected H-13 material. The H-13 was selected on the basis of both strength and compatibility with post-insertion DWAl sleeve heat treatment.

- Steel/DWAl Thermal Capability - After insertion assembly of the DWAl sleeve into the steel casing, heat treatment of the DWAl does not affect the yield strength of the selected H-13 steel casing. In addition, the coefficient of thermal expansion values of the steel and DWAl tubes are reasonably close (on the order of 8 x 10^{-6}/°F for the DWAl and 6 x 10^{-6}/°F for the steel) for a favorable thermal match during solution treat and quench.

- Weight Savings Considerations - The primary weight reduction mechanism used was to replace a significant portion of the previous steel track pin with DWAl 20®, thus reducing the weight of that section by about one-third. The reinforcement used in the selected DWAl system was SiCp for reasons of producibility, cost considerations, and abundant past experience. Using a lighter reinforcement such as B_4C could have further reduced pin weight but was not within the developmental scope of the program.

  The final selection of hybrid track pin component materials was:
  - H-13 tool steel outer casings;
  - 25v/o SiCp/6061-T6 inner sleeves.

5.2.2. Design Analysis. Having selected the steel and DWAl hybrid components (H-13 and 25v/o SiCp/6061), design analysis was concentrated on sizing to meet the requirement that the section (shown on next page) must withstand 11,000 pounds force applied in three-point bending on 19-inch separated supports.

Table 5-1. Typical Mechanical Properties of DWAl 20®

Matrix Alloy	15	20	25	30	35	40
6061	14 58 66 7.5	15 60 72 5	16.5 62 77 3.5	17.5 63 80 3.0	19.5 66 80 2.7	21 60 80 1.75
2124	-	-	16.5 62 88 4.5	18.2 70 90 2.5	-	22 75 100 1.1
7090	-	15 95 105 2.5	16.7 98 115 2.0	18.5 102 112 1.2	19 103 105 0.9	21 100 103 0.9
7091	14 84 95 4	15 86 98 3.5	16.5 90 104 2.5	18.5 90 100 2.0	-	20.2 90 95 1.2

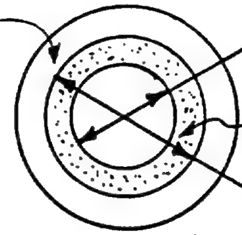
KEY

Modulus (10^6 psi)	Yield Strength (ksi)	Ultimate Strength (ksi)	Ductility (%)

PRODUCTION READY

Table 5-2. Candidate Steels for Pin Outer Casing Use

Designation	Yield Strength	Tempering Characteristics
17-4 PH	170 ksi	Stable for hours at 1000°F. Ok for DWAl heat treat.
17-7 PH	180 ksi	Stable for 1 hour at 1000°F. Ok for DWAl heat treat.
AM 350	175 ksi	Ok for exposure for 500 hours at 900°F. Ok for DWAl heat treat.
AM 355	175 ksi	(same as AM 350)
PH13-8 Mo	190 ksi	Ok for 1 hour at 1000°F. Ok for DWAl heat treat.
18 Ni (200) Maraging	220 ksi	8 hours at 950°F Ok. Ok for DWAl heat treat.
H-11	150 ksi	2 hours at 1000°F Ok. Ok for DWAl heat treat.
H-13	210 ksi	1 hour at 1000°F Ok. Ok for DWAl heat treat.



Bending stress at any radius "C" of the section is calculated from the flexure equation:

$$\sigma = \frac{Mc}{I} = E\frac{Mc}{(EI)_c}$$

Where:
- M = applied bending moment
- I = moment of inertia
- E = Modulus of Elasticity of material at "C"
- $(EI)_c$ = combined EI of hybrid pin
- c = distance from neutral axis

The applied stress, σ, is inversely proportional to the product EI. For a given allowable stress, the high value of EI permits high moment application.

Illustrated in Figure 5-3, variation of the parameter EI with the inside diameter D_i is presented as a function of mid diameter D_m. The mid diameter designates the interface location between the DWAl inner sleeve and the steel outer jacket. Further illustrated is the weight savings potential corresponding to the various constituent materials and configurations.

The correct ratio of cylinder diameters will affect the hybrid pin design in several ways:

- Weight savings;
- Pin deflection elastic constants, which in turn affect loads on the track block;
- Stress ratios, i.e., failure mechanisms that will control the mode of failure (ideally, the composite would fail exactly as would the steel).

5.2.3. Pin End Configuration. The pin end configuration shown in the design drawing, U.S. Army TACOM Part No. 12274418, is the same as for the modified hybrid design, as the units are interchangeable on the MBT.

5.3. Track Pin Fabrication

For the present lightweight pin development, the selected steel casings required gun drilling, honing, and outer diameter (O.D.) grinding. The extruded DWAl sleeves required O.D. grinding. However, in production, the tubular elements of the hybrid lightweight track pin would be extruded to nearly net dimensions, followed by the operations of heat treatment,

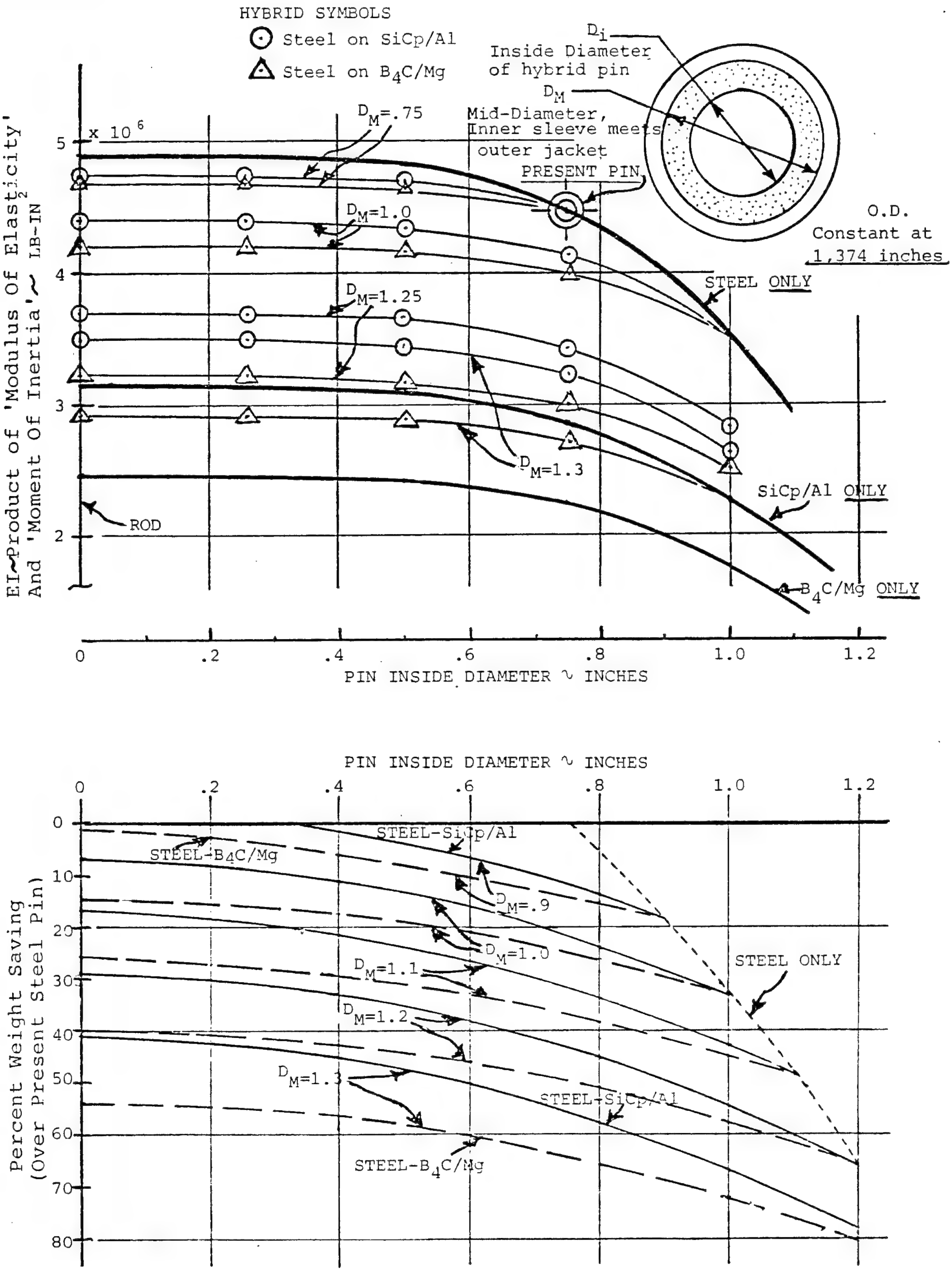


Figure 5-3. Overview of Candidate Pin Configurations, Comparing Potential Weight Savings

straightening, cutting to length, and insertion assembly. Only a minumum amount of precision machining would then be required to complete the track pins.

5.3.1. Tubular Parts Fabrication. At this date, most of the commercially available alloy steel tubing is extruded 4130. The higher strength alloys, such as the selected H-13 tool steel, are not generally available, and they require a special extrusion mill run to provide the outer steel casings. Inner sleeve DWAl 20® tubular extrusions may be produced from standard DWA billets by several aluminum extrusion facilities.

- Steel Casings. The available extruded 4130 steel tubing was used early in the program to: (1) demonstrate interference-fit techniques applied to the hybrid track pin, (2) provide casing units for development of the pin insertion assembly apparatus, and (3) furnish test material, with and without DWAl sleeve insertion, for early evaluation.

  Extruded H-13 round bar stock was selected from the candidate alloys listed in Table 5-2. The diameter of the round bar was required to be adequate for gun drilling followed by heat treat, honing, and O.D. turning/grinding, while maintaining concentricity without excessive distortion. Round bar diameter of 1-5/8 inches was selected for the gun drilling activity.

  After gun drilling, the heat treat operation imparted sufficient distortion to require nominal straightening before precision honing as required to match the steel inner diameter (I.D.) and the DWAl sleeve O.D.

- DWAl 20® Sleeves. A design analysis established the dimensions of DWAl 20® sleeve tubing extrusions. Two aluminum extrusion facilities were selected based on previous experience with DWAl 20®, particularly extrusion of tubes. The two companies are Martin Marietta, Torrance, California and RMI Company, Extrusion Plant, Ashtabula, Ohio.

  Initial DWAl tubing, for preliminary activities with 4130 steel casing, was extruded by Martin Marietta. An existing extrusion die set was modified to provide for the required tubing. This die set produced tubes by extruding over a bridge. This is typical of aluminum extrusions and requires parting the material and self rewelding inside the die cavity.

  After selecting the final hybrid pin component dimensions (for both steel and DWAl 20® tubing) it was decided to use the equipment and expertise available at RMI to extrude the DWAl tubing to the specified dimensions, using a die and mandrel set that requires prior drilling of the billet. After cutting to sleeve length and straightening, the DWAl tubes were centerless-ground to the proper outside diameter for shrink-fit insertion assembly in the H-13 steel casings.

5.3.2. Pin Insertion Assembly. The interference shrink-fit technique of pin insertion assembly was used to produce the hybrid MBT track pin. For consistent track pin assembly, adherence to the following guidelines was required:

- component tubes dimensional match;
- proper alignment and high insertion rate;
- compatible Coefficient of Thermal Expansion (CTE) values of DWAl and steel to insure post-insertion heat treatment with minimum distortion.

The final casings and sleeves are shown in Figures 5-4, 5-5, and 5-6. The steel casings were heat-treated before final honing to account for any movement experienced during the heat treat process. However, the DWAl sleeves were heat-treated in place after being inserted. Accordingly, to prevent excessive DWAl yield during solution treat, the CTE values of the DWAl and steel had to be close in magnitude.

For insertion assembly, the DWAl sleeve was positioned above and in vertical alignment with the steel casing. The casing was heated to approximately 1100°F so that the I.D. expanded sufficiently to accept the DWAl sleeve O.D. which, when both components were at room temperature, was about .0015 inches larger than the casing I.D.

5.3.3. Pin End Configuration Forming. The DWAl 20® and H-13 steel, hybrid, lightweight track pin is required to be interchangeable with TACOM Part No. 12274418 which defines the pin end configuration design details. To comply with strength and fatigue criteria, the wall thicknesses of the DWAl sleeve and steel casing were established, determining the method of forming the pin end configuration.

Basically, two schemes are applicable to providing the required contour of the track pin ends, depending on the outer casing wall thickness. If this wall is sufficiently thin, a crimp-forming method applies. However, for outer casing wall thickness greater than the contour depth, machining the end configuration becomes necessary.

Early in the contract effort, it was convenient to use thin wall 4130 steel outer casing tube. This tubing was readily available commercially and was compatible with DWAl sleeve tubing existing in DWA inventory; it was also practical to extrude using existing extrusion tools. The steel tube wall thickness was thin enough to permit crimp-forming the end contours.

Initial pin end crimp-forming required a closed forming die set by which the steel casing at the pin end location was bent into the required shape, forging the inner DWAl sleeve to match. Ejection pins facilitated removal of the track pin from the die; the excess flash from the DWAl sleeve was removed, and the required end section tolerances were machined as necessary.

For the final track pin, the steel casing tube wall was sufficiently heavy to require machining of the end configuration completely.

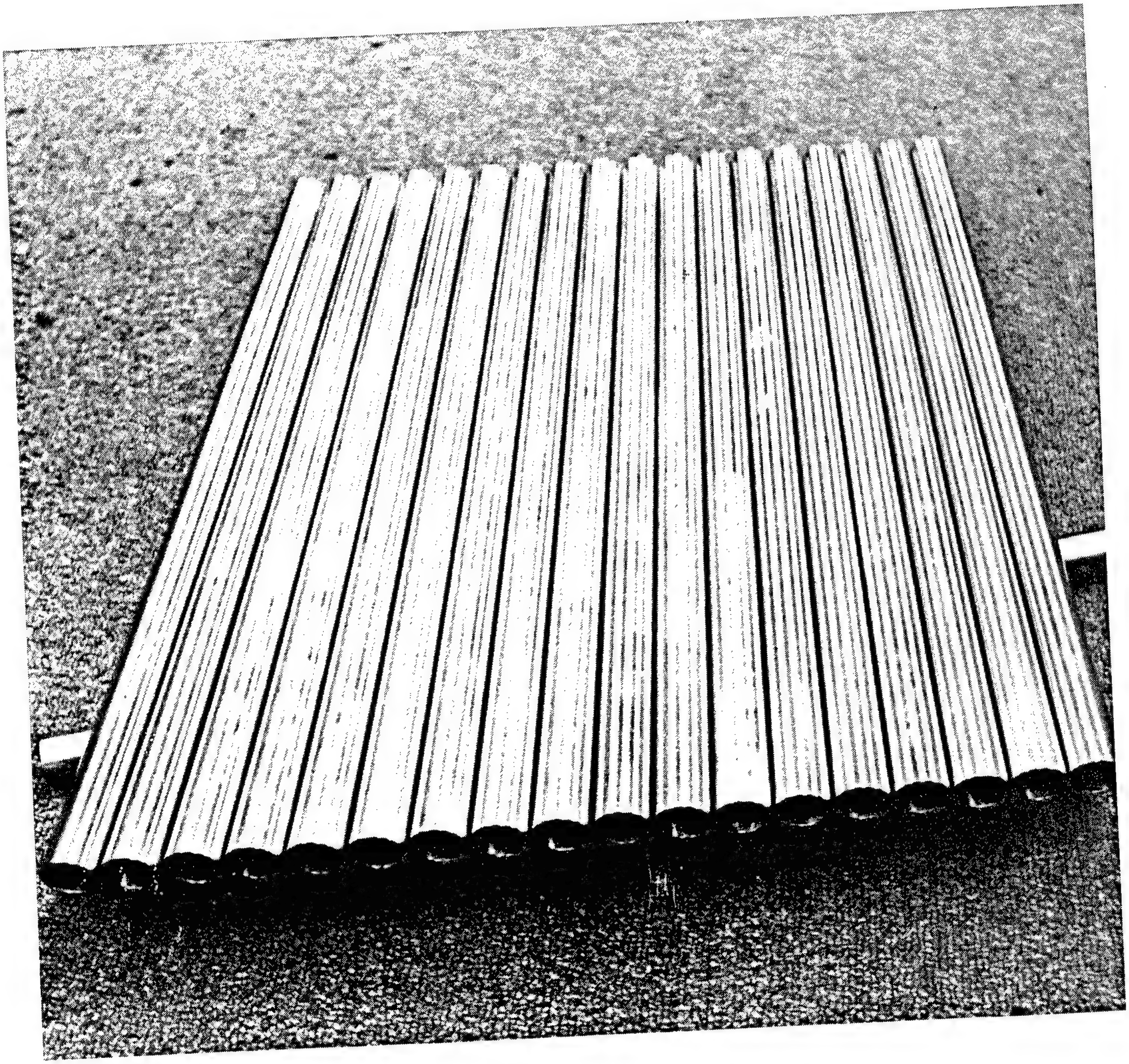


Figure 5-4. H-13 Steel Casings for Hybrid Track Pins.

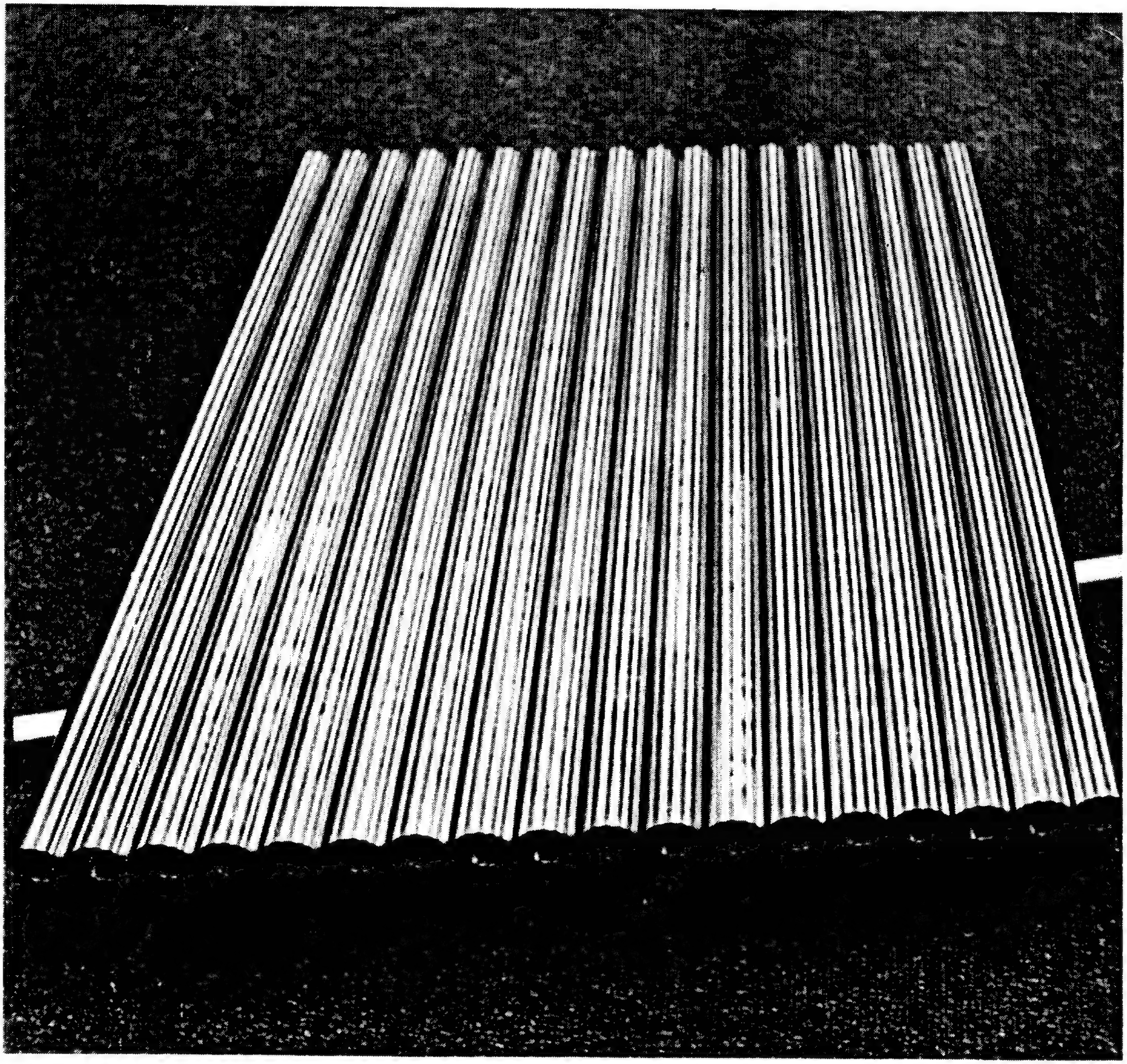


Figure 5-4. H-13 Steel Casings for Hybrid Track Pins.

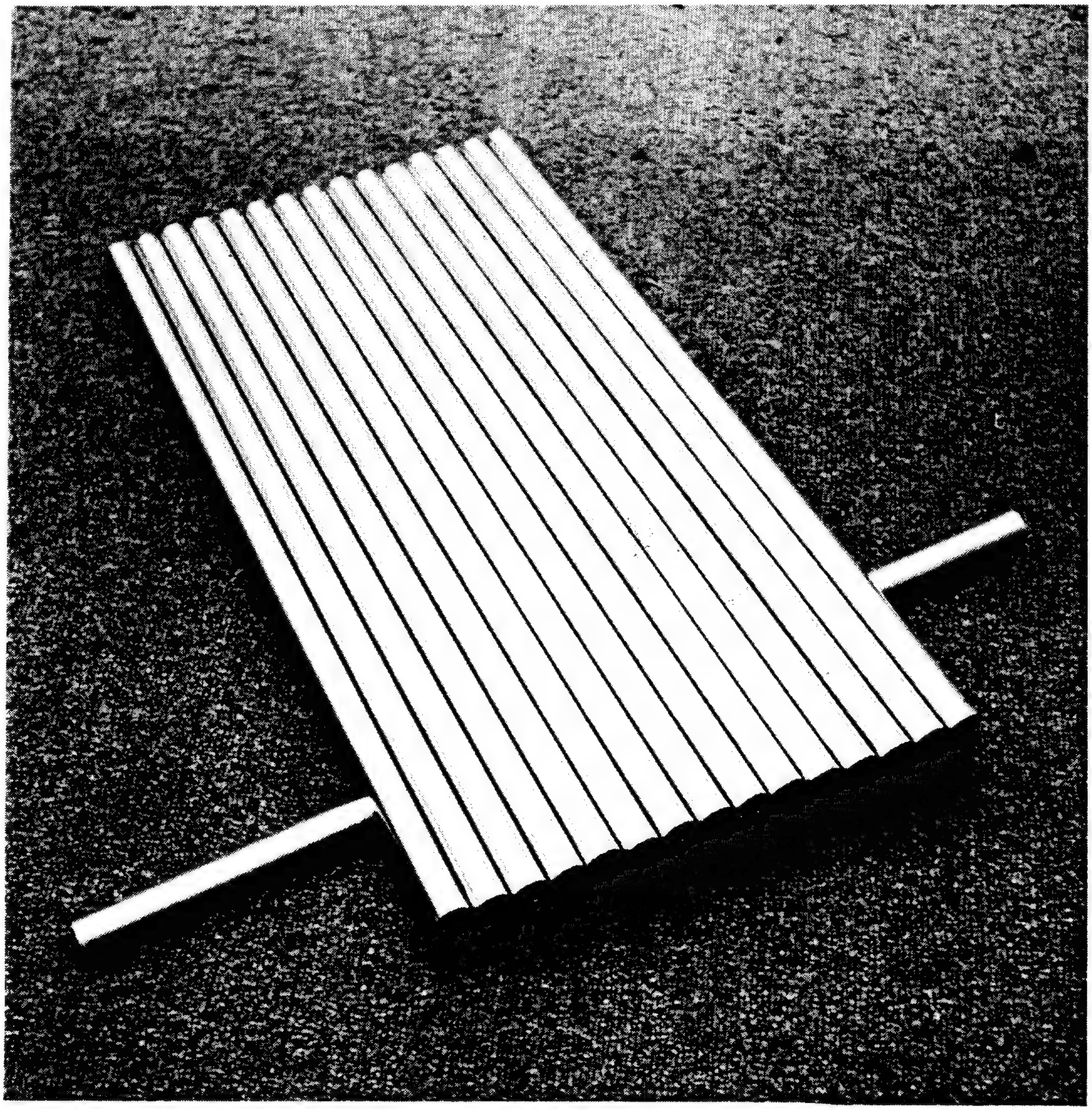


Figure 5-5. DWAl 20® MMC Liner Sleeves for Hybrid Track Pins

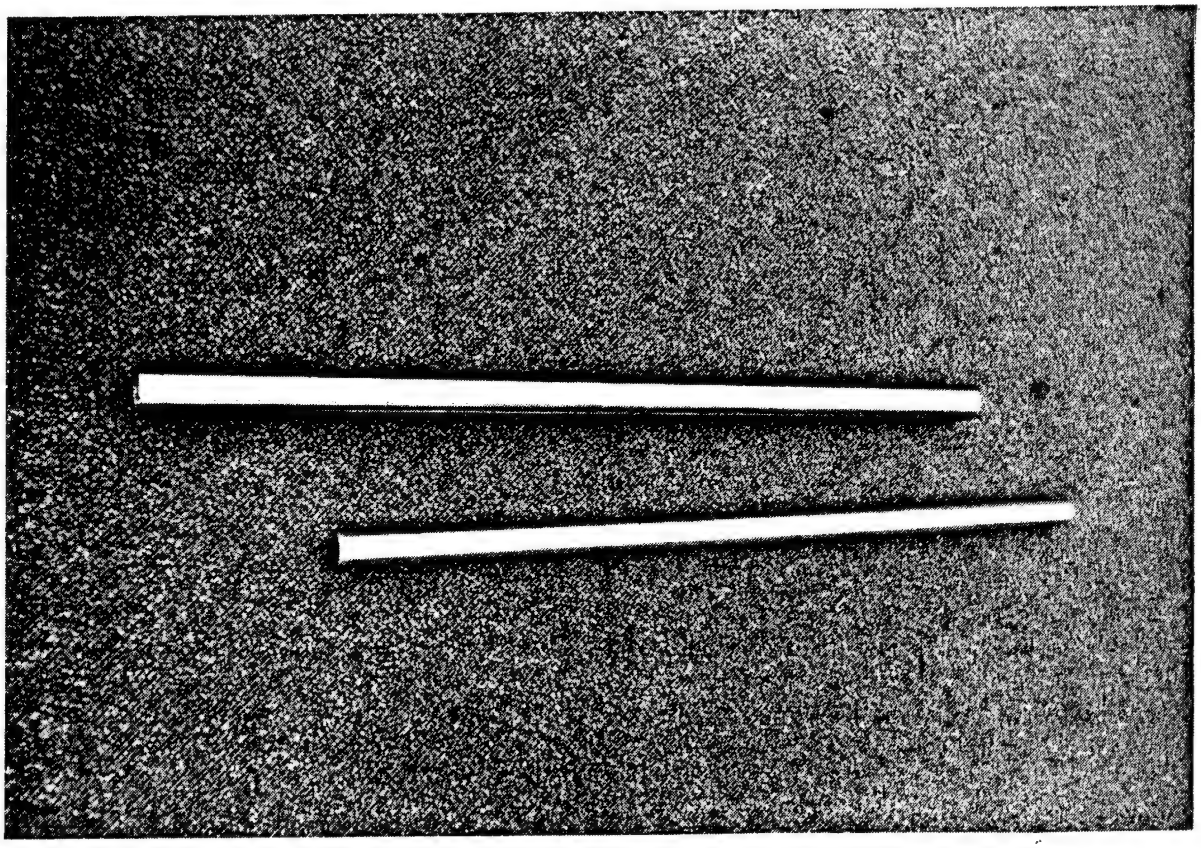


Figure 5-6. Matched Pair of H-13 Steel Casing and DWAl 20® MMC Liner

5.3.4. Hybrid Track Pin Heat Treatment. Heat treatment of the hybrid track pin was clearly complicated by the integration of dissimilar metals, each requiring radically different heat treating techniques. Accordingly, one of the criteria for material selection involved steel and DWAl mutual compatibility with the temperature requirements of heat treatment. The selection of H-13 was based primarily on the criterion that the steel Coefficient of Thermal Expansion (CTE) be compatible with that of DWAl 20®. Further, the temperatures required for inteference fit, and solution-treat of the DWAl sleeves after insertion assembly, must not reduce significantly the steel casing strength.

The casing heat treatment was done by National Heat Treat (NHT) Company, Tarzana, California to RC 50 hardness in accordance with the method specified for AISI Type H-13. Straightening was done by NHT during the heat-treating process.

The DWAl 20® sleeves (25v/o SiCp/6061) were inserted in the steel casings in the "not in the heat-treated" condition. Straightening was done prior to insertion to insure efficient assembly. After insertion, the pin assembly containing the DWAl sleeve was heat-treated according to specification DWA-84-225, bringing the DWAl 20® sleeve to the T6 condition, i.e., solution treatment of one hour at 1000°F, and water quench and age at 325°F for five hours.

5.4. Pin Fabrication and Assembly Equipment

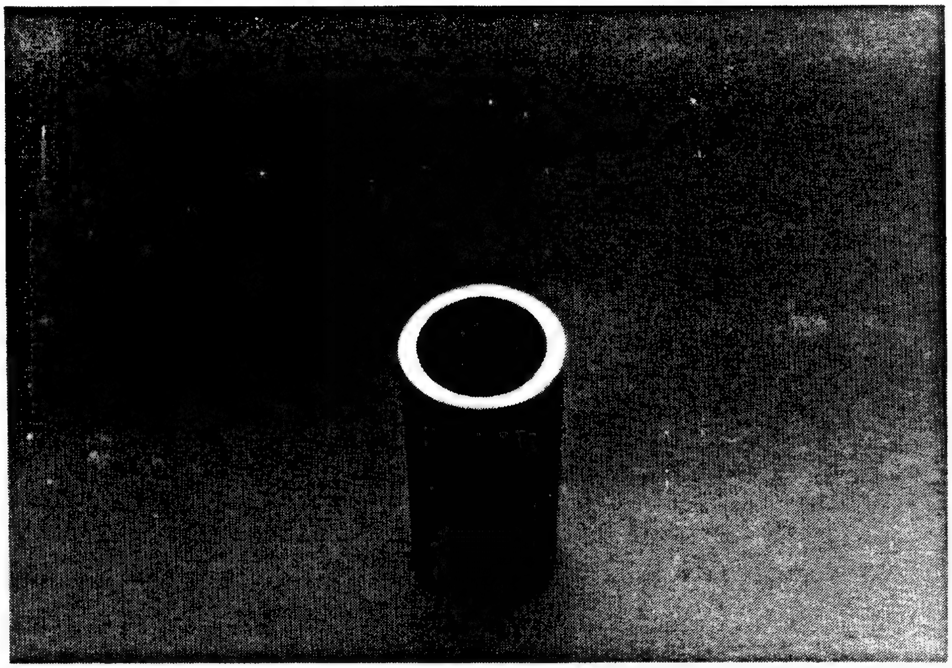
Conventional machines and methods were used to fabricate the two components comprising the hybrid lightweight track pin. However, insertion assembly and pin end configuration forming both required unique equipment, described in the following paragraphs.

5.4.1. Pin Insertion Assembly Apparatus. The hybrid track Pin Insertion Assembly (PIA) apparatus consisted primarily of a heated receiver chamber for locating and heating the steel casing, and a hydraulic ram positioned directly above, designed to insert the DWAl sleeve into the steel casing when alignment and temperature conditions were correct.

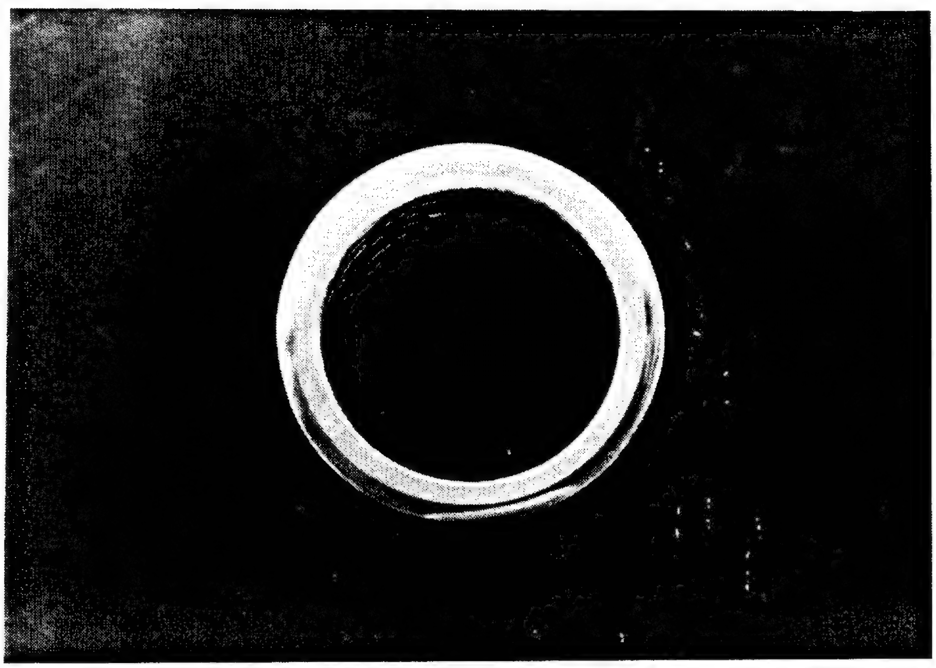
Development of the PIA was divided into three phases:

- Manual Feasibility Demonstration;
- Automatic, Pneumatically-actuated System Synthesis;
- Modificaiton to Hydraulic Operation.

The first manual experiments consisted of insertion of short sections of DWAl tubing into steel casings, thereby demonstrating shrink-fit assembly. A steel tube with outside diameter of 1.374 inches at room temperature was heated in an oven to approximately 1000°F. A sample tube of DWAl 20®, 20v/o SiCp/6061, with an outside diameter 0.002 inches larger than the steel jacket inside diameter at room temperature, was inserted manually into the hot steel tube. When the assembly returned to room temperature, the shrink-fit was done. The assembly is illustrated in Figure 5-7, normal size and magnified. Continuing with manual experimentation, the component



Subsize Hybrid Pin Section, 4130 Steel Jacket Enclosing DWAl 20® Tubular Sleeve, 20v/o SiCp/6061



Magnified View Showing Inner DWAl Sleeve and Outer Steel Jacket

Figure 5-7. Initial Hybrid Pin Section Resulting From Thermal Interference Shrink-fit Experiment

tube lengths were increased to verify insertion assembly applicability to the operational pin size.

For this demonstration, a simple preliminary PIA unit was constructed as illustrated in Figure 5-8, showing the basic framework, the preheated steel jacket with mechanisms to hold aligment, and the DWAl sleeve being inserted manually from above through an alignment tube. For this activity, the steel tube wwas heated in an oven, then positioned rapidly by an angle-shaped fixture beneath the DWAl sleeve for a quick insertion by hand. Several full-length pins, using the initial steel and DWAl components, were completed.

Two features were next added to the PIA: an integral oven for heating the steel casing in place up to insertion temperature, and a pneumatic ram for automatic insertion-assembly of the DWAl sleeve. Also included was a four-way valve and an accumulator tank to increase actuator efficiency. The oven was composed of three radiant heaters surrounding the steel casing. Pneumatic power was provided by a higher pressure nitrogen gas source. The pneumatic system was sufficient for the preliminary track pins, providing early experience for development of criteria leading to the final hydraulic PIA. The finalized pneumatic system is described in the sequence of photographs, Figures 5-9 through 5-15.

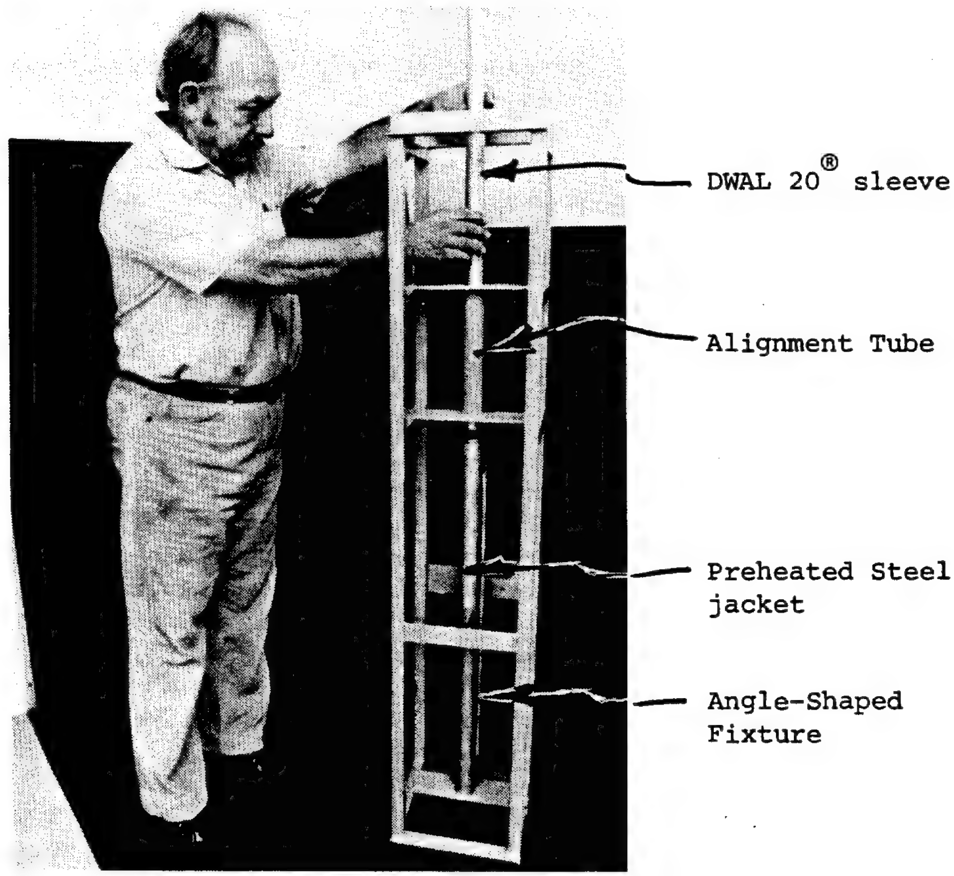
- Hydraulic-powered Pin Insertion Assembly Apparatus. The final hydraulic-powered unit was previously illustrated in Figure 1-1. The pump/motor subsystem is shown in Figure 5-16, including a reservoir tank containing an adequate hydraulic oil supply.

  Many improvements were incorporated during the transition from the pneumatic to the hydraulic system. The accumulator was moved to the top of the unit to help minimize pressure loss; the infrared heaters were replaced with a more easily controlled and efficient ceramic oven; control valves were added for automatic cycling (rapid insertion and slow retraction). A system schematic of the hydraulic unit is presented in Figure 5-17.

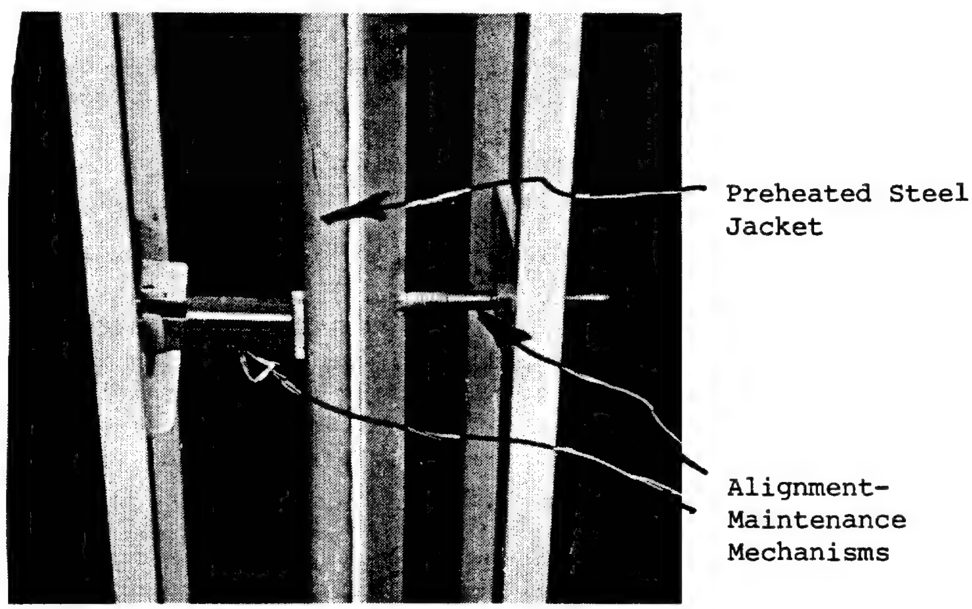
5.4.2. DWAl Sleeve Cooling System. Interference fit can be done by heat-expanding the casing and/or cold-shrinking the DWAl sleeve. For example, after heating the steel casing to the temperature corresponding to the appropriate dimensional increase, the DWAl sleeve may or may not need to be cooled before insertion, (depending on the straightness of both component tubes and on the steel heat-up uniformity). One cool-down method is to insert a cryogenic medium into the free end of the DWAl tube, with insertion triggered immediately thereafter.

5.4.3. Steel Casing Heat-up System. Three methods were evaluated experimentally leading to development of the selected subsystem for steel casing preinsertion heat-up. These methods, with performance illustrated in Figure 5-18, included:

- Heating the casing to insertion temperature in a separate oven, then positioning the heated steel tube beneath the DWAl sleeve which is immediately inserted. Problems encountered involved mainly handling and excessive cool down during alignment.



PIN ASSEMBLY APPARATUS



CLOSE-UP OF ALIGNMENT MAINTENANCE

Figure 5-8. Tank Track Hybrid Pin Insertion Apparatus for Thermal Interference Shrink-fit Assembly

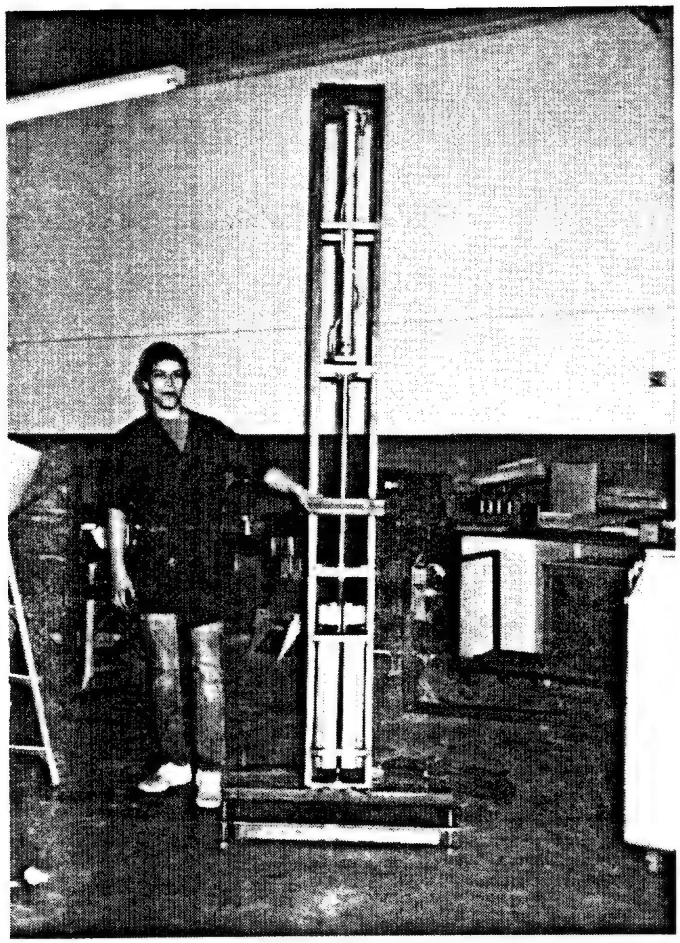


Figure 5-9. Refined Pin Insertion Assembly (P.I.A.) Apparatus for Shrink-fit Assembly of TACOM DWA1 20® and Steel Tank Track Pins

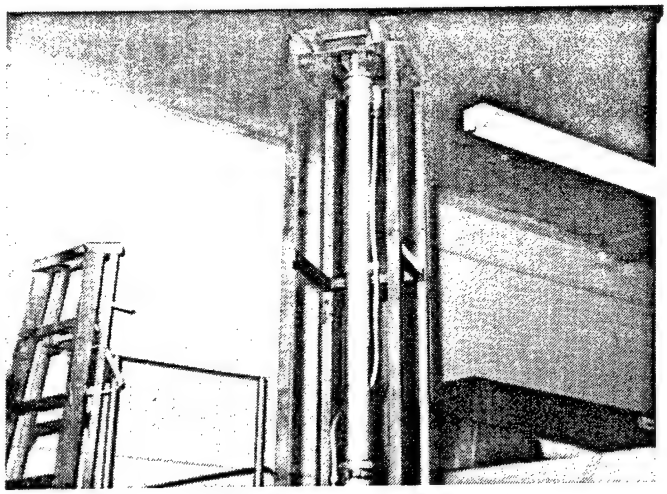


Figure 5-10. Actuator Installation on P.I.A.

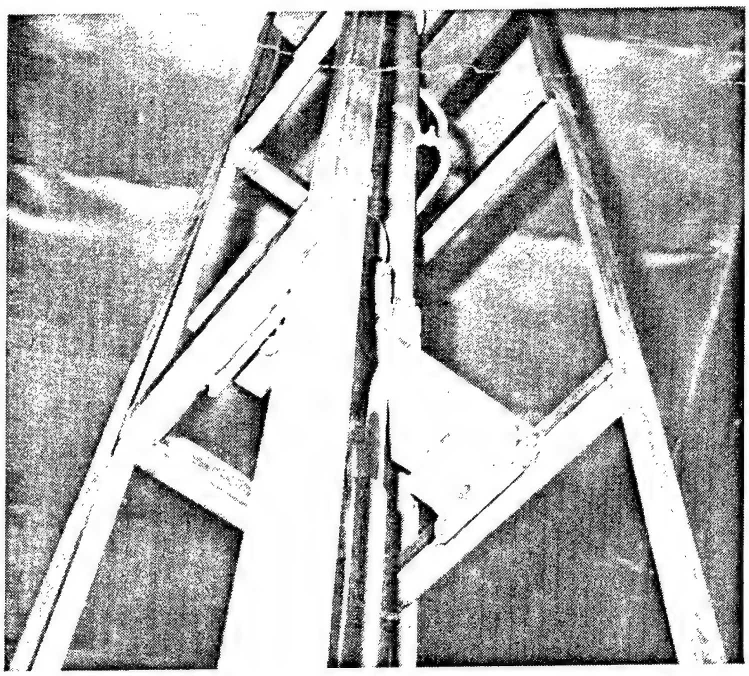


Figure 5-11. Central View of P.I.A. Structure

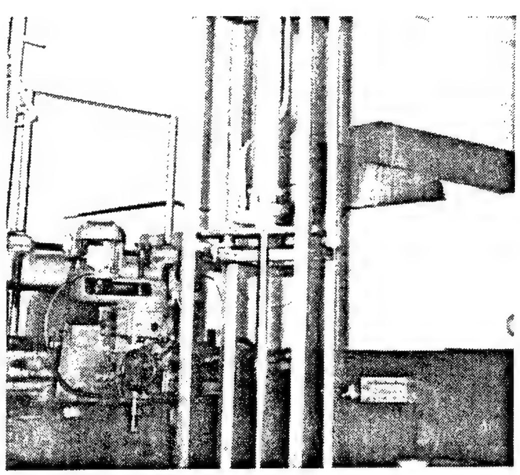


Figure 5-12. View of P.I.A. Piston Extended

Figure 5-13. View of P.I.A. Four-way Valve.

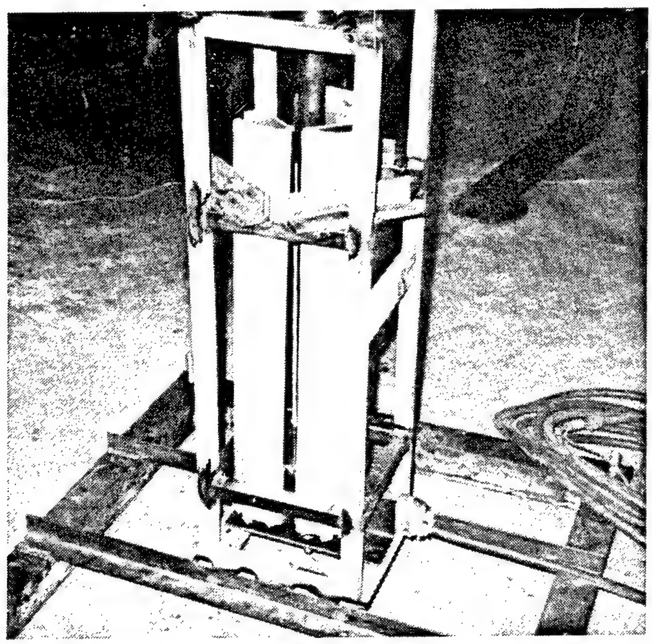


Figure 5-14. P.I.A. Infrared Heating Chamber

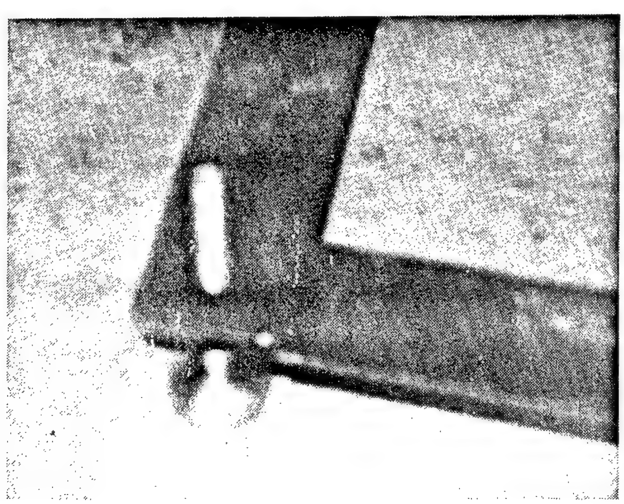


Figure 5-15. P.I.A. Leveler Installation on Corner of Base Frame, One of Four

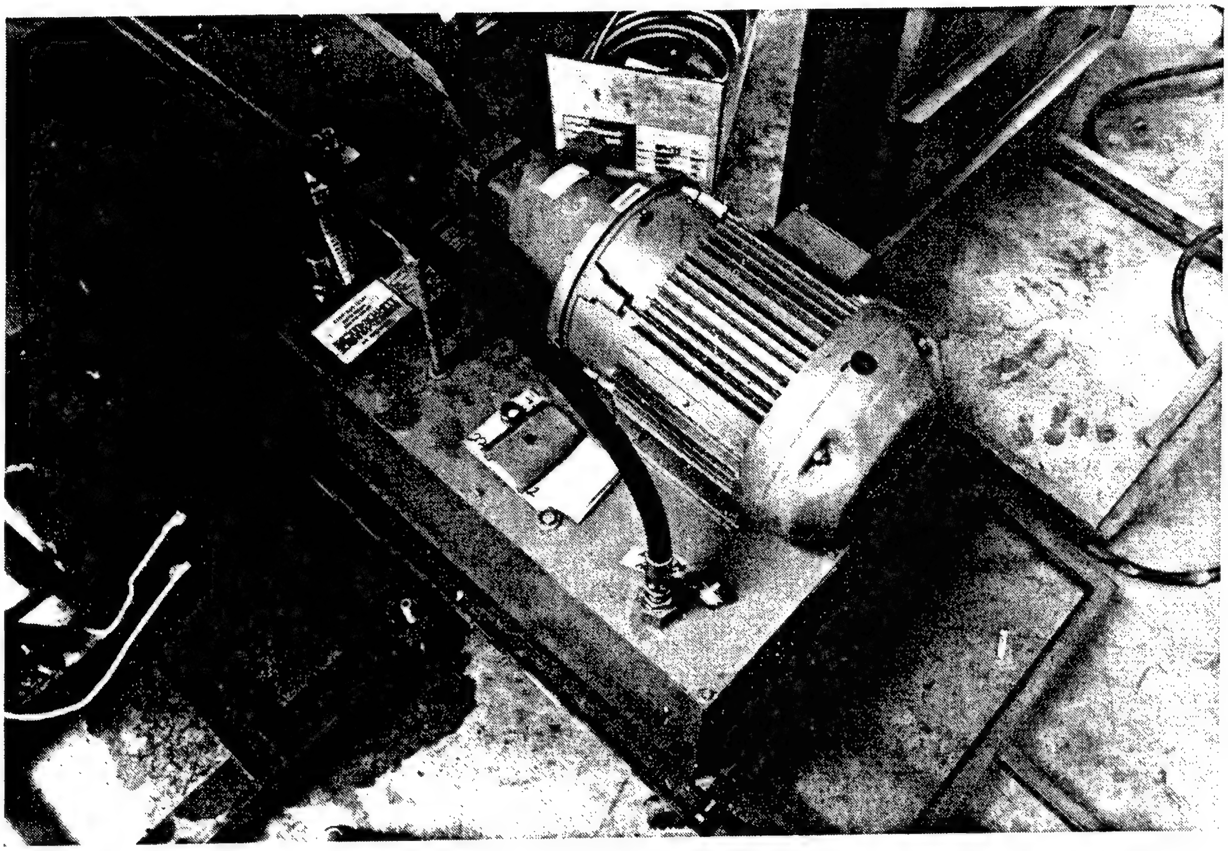


Figure 5-16. Hydraulic Power Unit Used to Power the TACOM Pin Insertion Assembly Apparatus

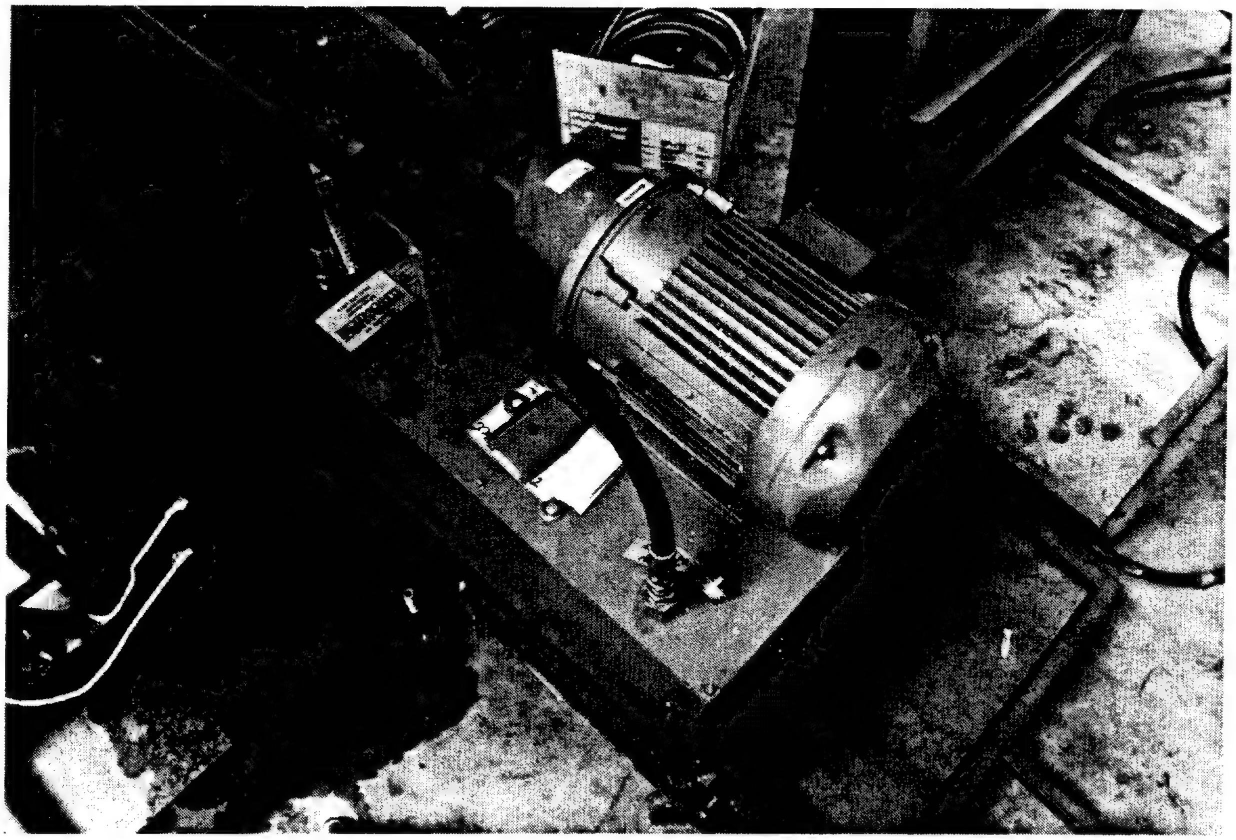
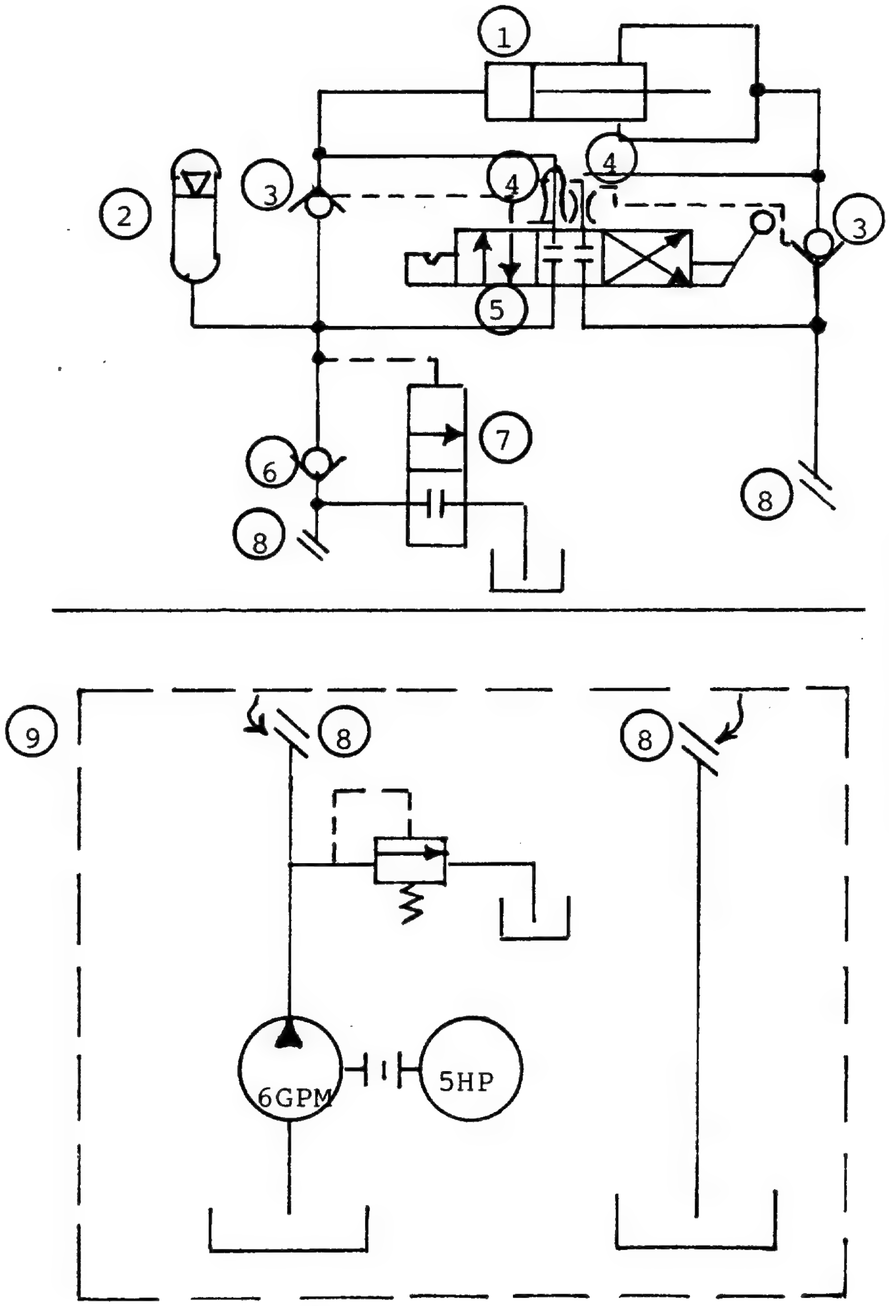


Figure 5-16. Hydraulic Power Unit Used to Power the TACOM Pin Insertion Assembly Apparatus



LEGEND

1. Main Hydraulic Ram
2. Oil-air Accumulator
3. Pilot-operated Chk Valve
4. Needle Valve
5. Four-way Directional Valve
6. Rt. Angle Check Valve
7. Unloading Valve
8. Male Quick-Disconnect Nipple
9. Hydraulic Power Unit

Figure 5-17. Schematic Diagram of Hydraulic-powered Pin Insertion Assembly Apparatus

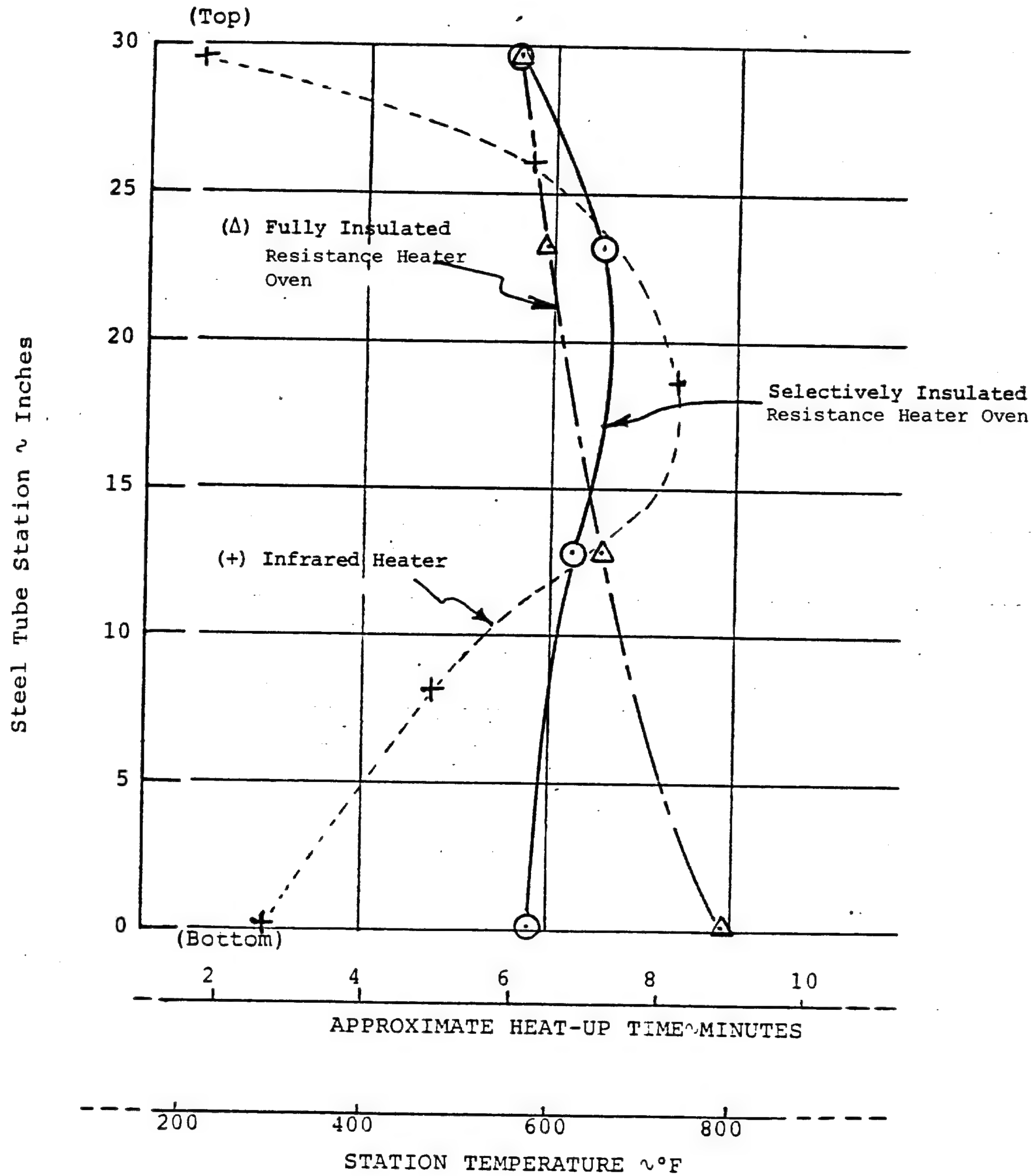


Figure 5-18. Influence of Heating Method on Efficiency of Heat Transfer to the Steel Casing

- Prepositioning the steel casing centered within a zone heated by infrared lamps. Difficulties included uneven heating of the steel tube longitudinally. By selective insulation, the temperature gradients were reduced but not to a level judged acceptable.

- Using a cylindrical ceramic oven (ceramic tube with nichrome heating elements) with the oven wall in close proximity to the steel tube. This method proved to be more efficient and adaptable to scale-up for future production apparatus, and was therefore selected for the final pin insertion assembly equipment.

5.4.4. Pin End Forming Tool. When the steel casing wall thickness is equal to or less than the depth of the pin end contour, a crimp-forming tool is applicable. Such a tool was used to form the end configuration of the initial thin wall casing pins. The equipment used, described in Figure 5-19, was composed of a die set, a plug unit, and a special punch. The punch was machined to the precision tolerances specified for the TACOM pin ends, thereby forming the required contour into the pin end when the pin is inserted into the tool, heated, and pressed. The crimp-forming tool components are shown in Figures 5-20 through 5-26, illustrating how the apparatus was used. A successful pin with crimped ends is illustrated in Figure 5-27.

For the final hybrid pins, the H-13 steel outer casing wall thickness exceeded the contour depth by about 0.020 inches. The required end configuration was therefore machined by precision grinding into each pin end. The finished machined pin-end configuration is illustrated in Figure 5-28.

6.0. MECHANICAL PROPERTIES AND TESTING

Selection of the pin material and configuration was based mainly on the mechanical properties of the candidate DWAl 20® and steel materials. These properties, over the temperature range specified, are summarized in the following paragraphs. Static and fatigue testing procedures and results are described, and nondestructive evaluation (NDE) of the hybrid track pin is discussed.

6.1. DWAl 20® Sleeve Mechanical Properties.

Mechanical properties of the selected DWAl 20® system are presented in Figure 6-1 based on previously established values and on results of tests conducted specifically for this development effort. (Table 5-1 compared the selected system with other DWAl systems at room temperature.) Shown in Figure 6-1 are variations of ultimate tensile strength and yield tensile strength for the DWAl 20® system used in the track pin sleeves (25v/o SiCp/6061). Sources of the test data presented include:

- DWA material property data bank.

- Reference 1, Raytheon Interim Report, Phase II, Naval Surface Weapons Center (NSWC) Contract N60921-82-C-A147, August 1984.

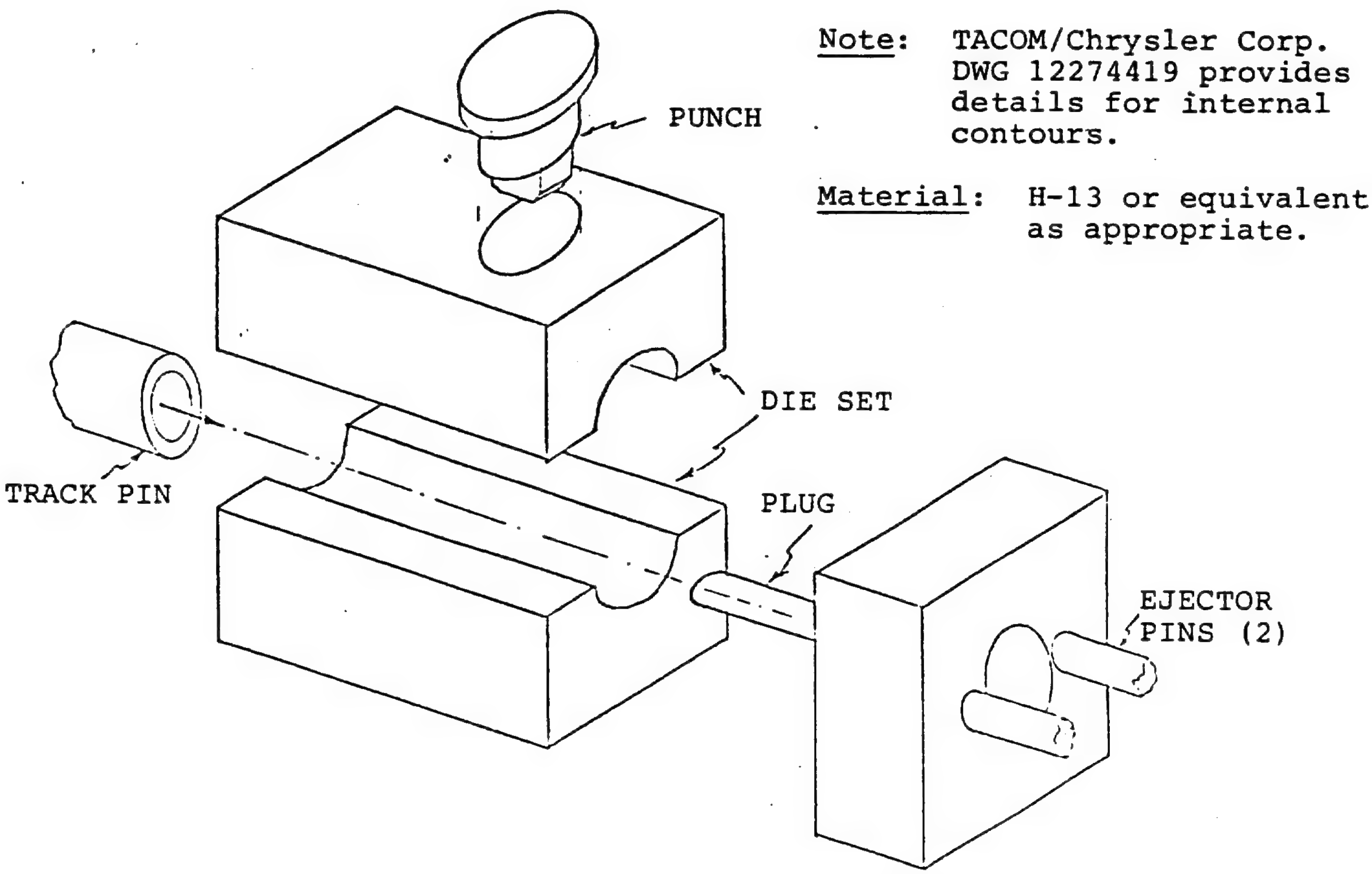


Figure 5-19. Crimp-forming Tool for Shaping Ends of DWAl 20© and Steel Track Pins

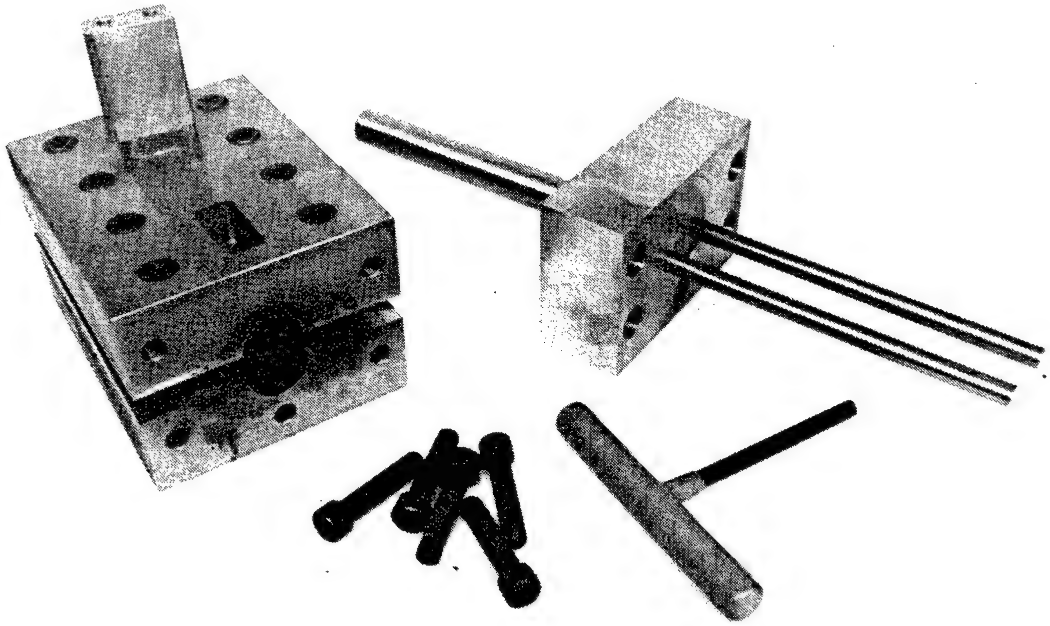


Figure 5-20. Component Parts of Pin-end Crimp-forming Tool

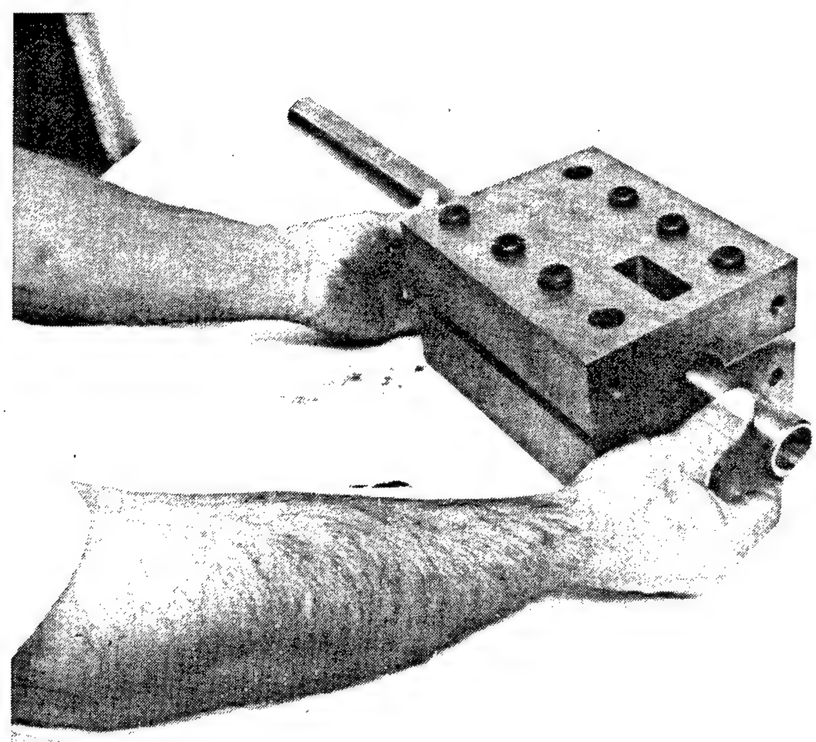


Figure 5-21. Installing DWAl 20® and Steel Track Pin into Pin-end Crimp-forming Tool

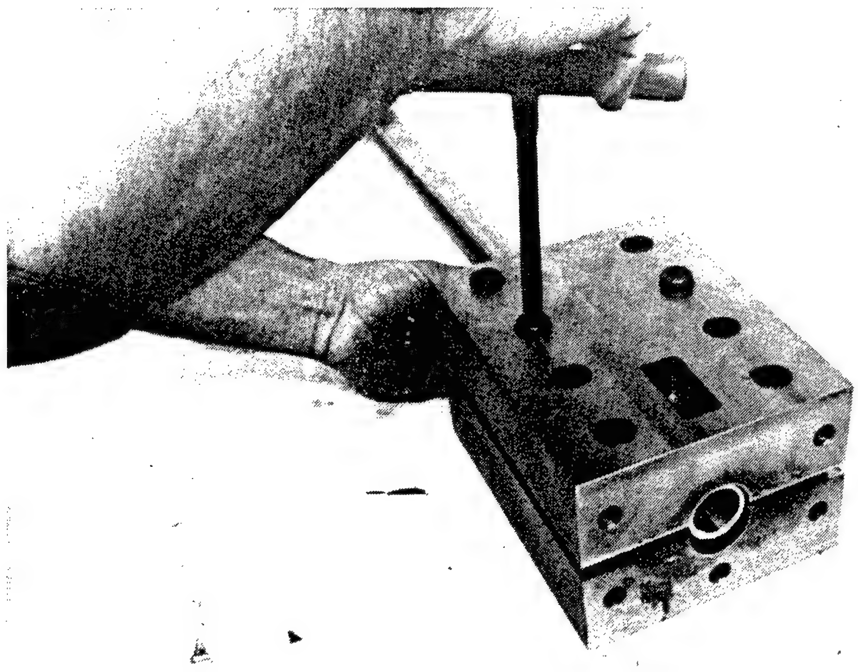


Figure 5-22. Securing Die onto DWAl 20® and Steel Track Pin in Preparation for Crimp-forming

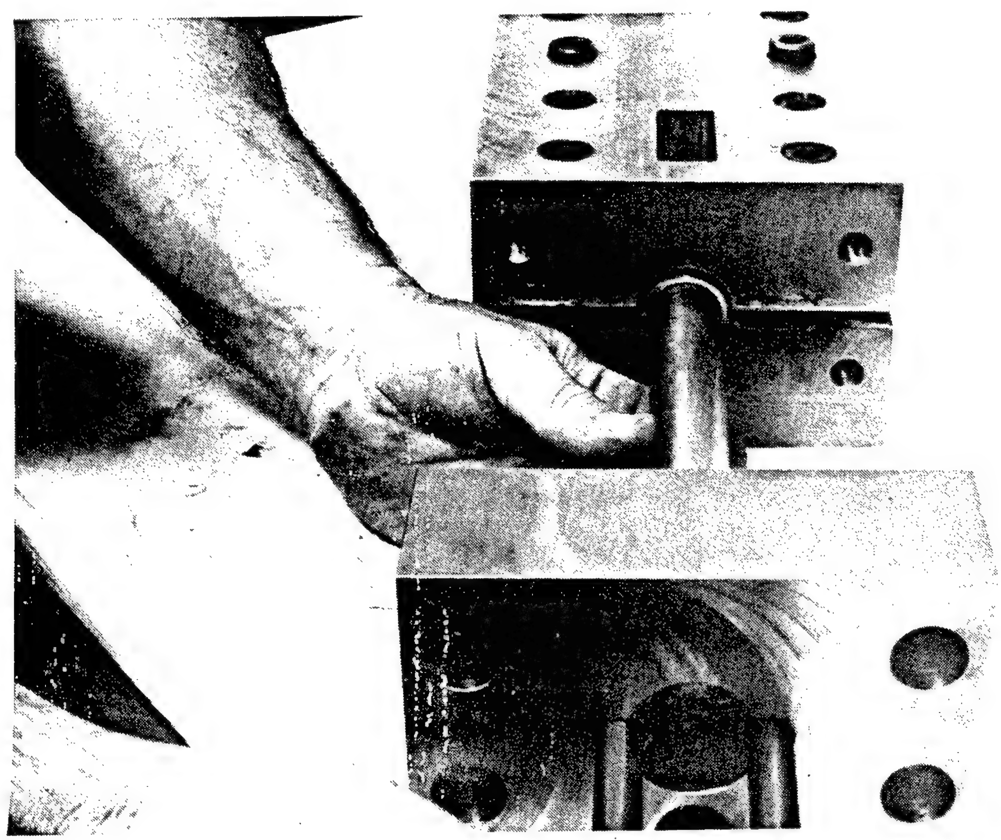


Figure 5-23. Inserting Inner Plug into Installed DWAl 20® and Steel Track Pin

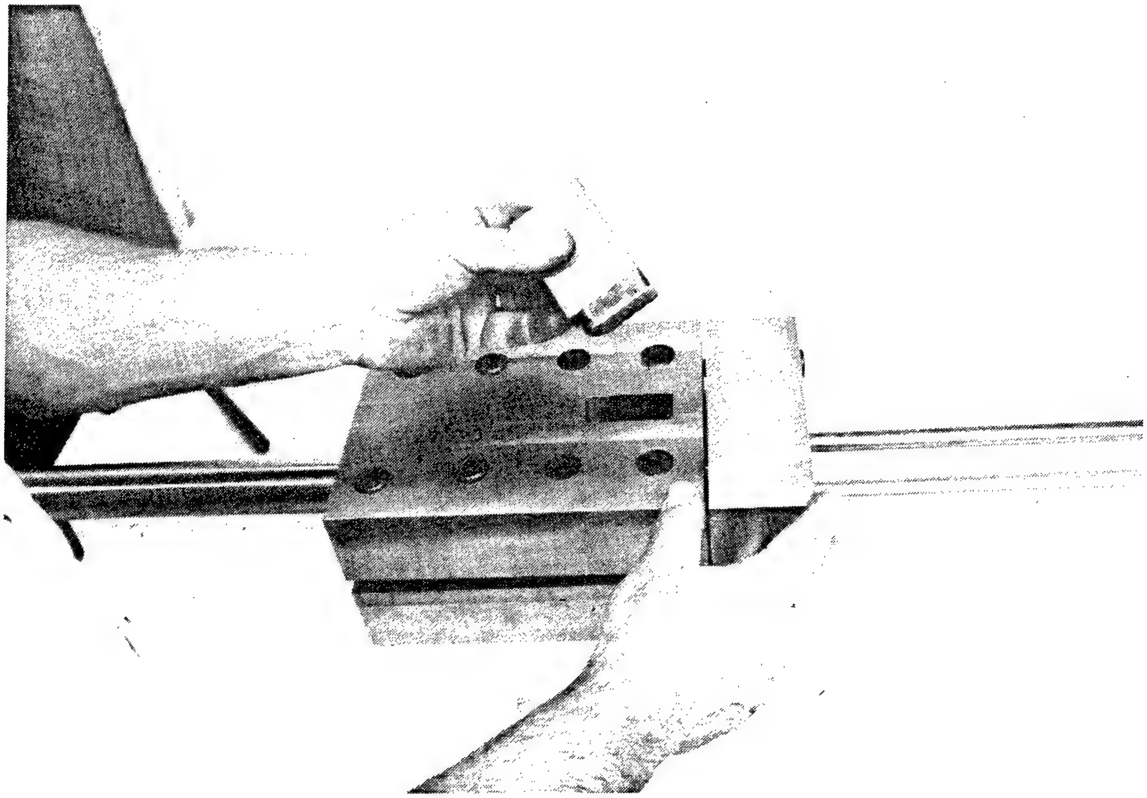


Figure 5-24. Inspecting Fit-up of Punch-to-die Cavity for Pin-end Shaping

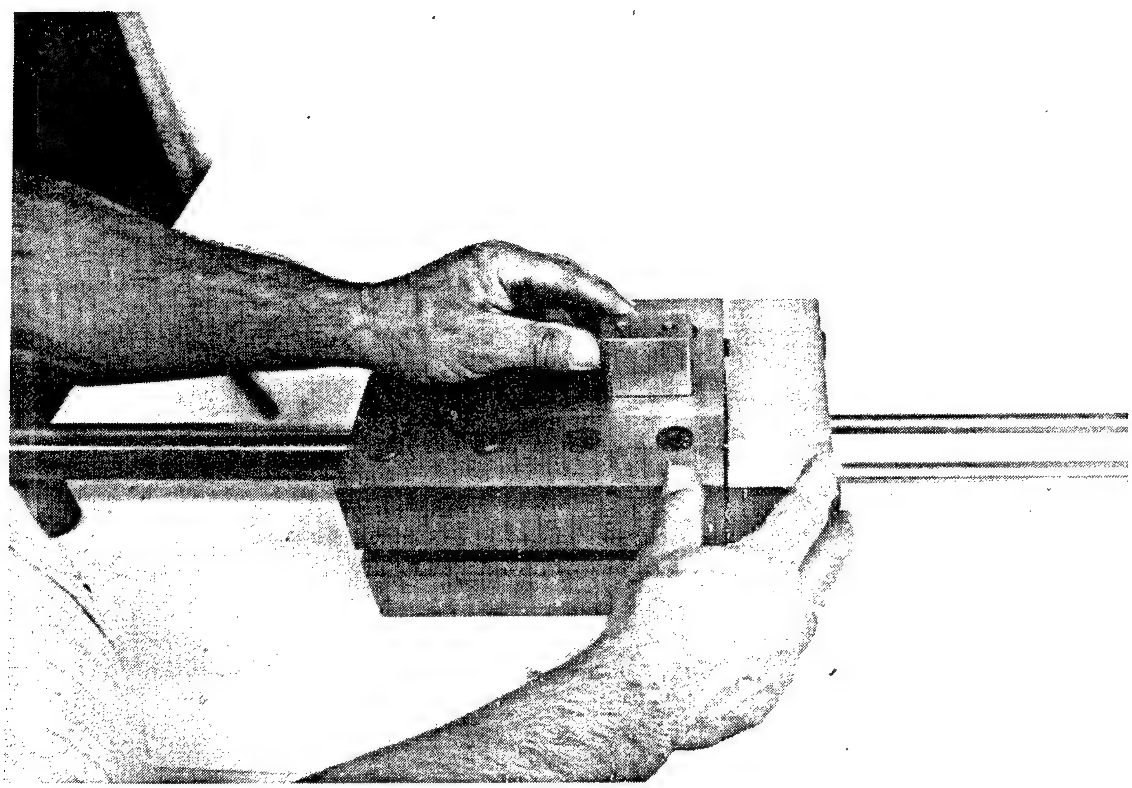


Figure 5-25. Final Inspection of Punch-to-die Cavity Before Pin-end Shaping

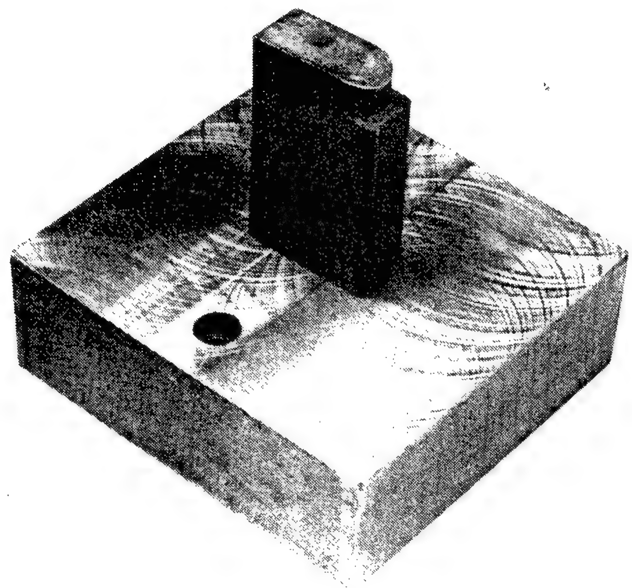


Figure 5-26. Pin-end Crimp-former Punch Installed on Pressure Plate to Prevent Cocking During Pin-end Shaping Operation

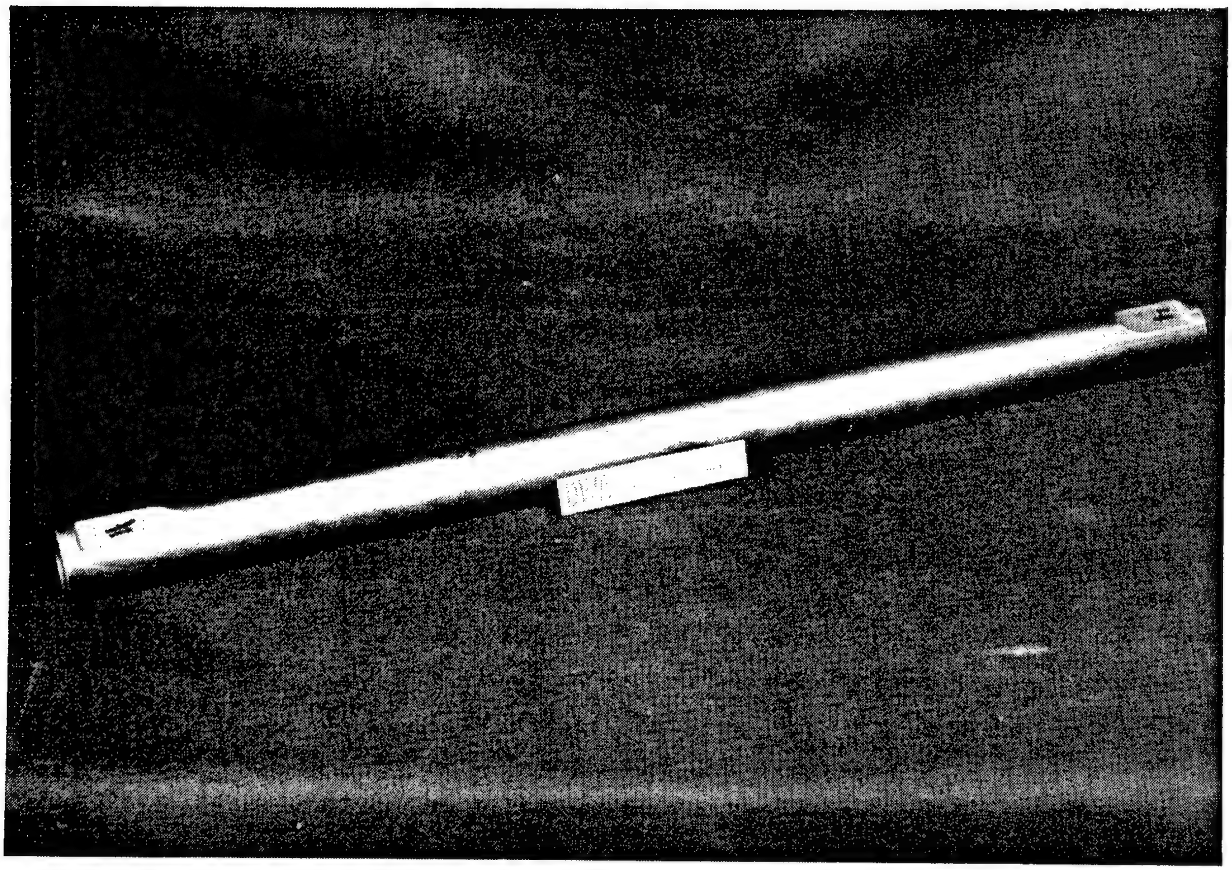


Figure 5-27. DWAl 20® and Steel Track Pin with Crimp-formed Ends

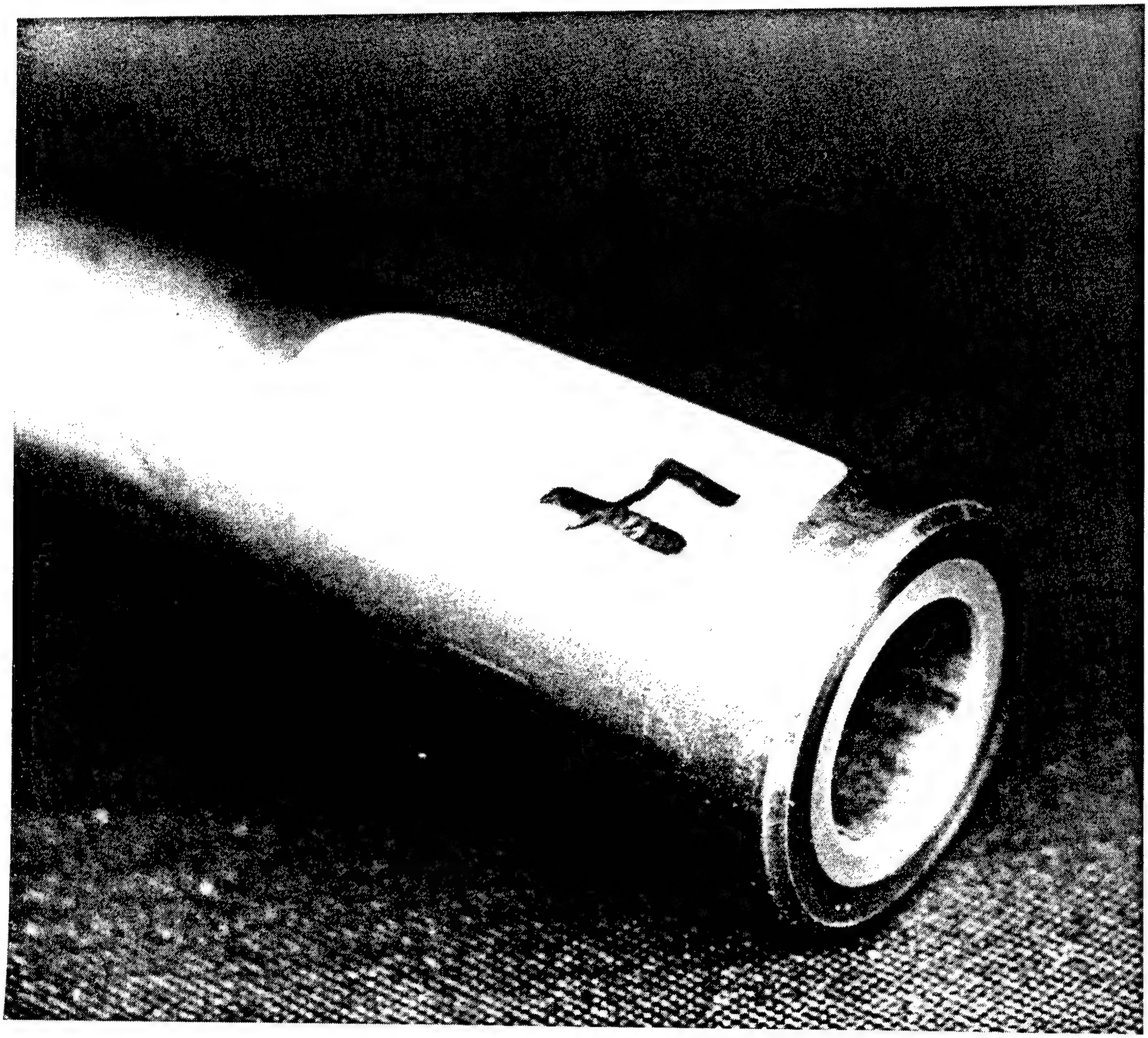


Figure 5-28. Finish-machined Pin-end Configuration of a Final Hybrid Track Pin

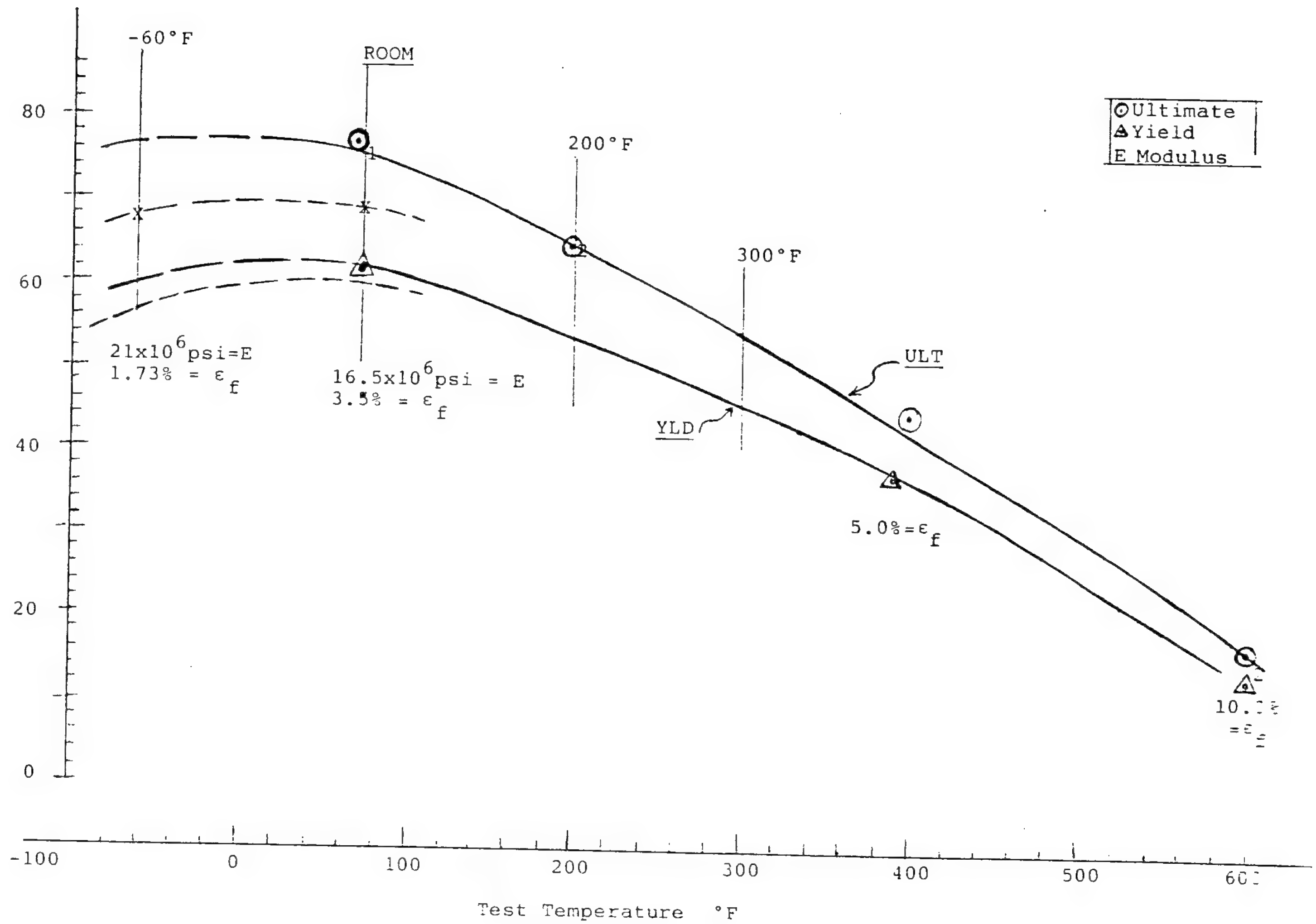


Figure 6-1. Tensile Properties of the DWAl 20® System Selected for the Track Pin Sleeve

- Reference 2, DWA Final Report, Phase II-F, Defense Advanced Research Projects Agency (DARPA) Contract N00024-80-C-5637, March 1983. (DWA Job 600.)

- Reference 3, DWA presentation to U.S. Army, Contract DAAG46-82-C-0031. (DWA Job 749.)

- Reference 4, DWA Final Report, Naval Surface Weapons Center (NSWC) Contract N60921-83-C-0004, July 1983. (DWA Job 826.)

- Reference 5, DWA Final Report, David W. Taylor Naval Ship R&D Center (NSRDC) Contract N00167-81-C-0059. (DWA Job 654.)

Also presented are notch toughness properties in Table 6-1, from Reference 4.

Abrasion resistance measurements are contained in Reference 5 which established that DWAl 20® threaded fasteners (#10-32) can be inserted repeatedly to full torque into threaded holes in steel without showing evidence of galling after 50 insertions. This experiment was conducted repeatedly with identical results.

Wear testing also indicated a nongalling behavior when DWAl 20® specimens were oscillated continuously under load against a DWAl 20® block. Most wear testing of DWAl 20® to date has been comparison testing, i.e., an apparatus simulating an operating environment with test blocks of DWAl 20®, aluminum, and steel in direct substitution. Using the apparatus illustrated in Figure 6-2, the data presented in Figure 6-3 were generated.

6.2. H-13 Steel Casing Mechanical Properties

Presented in Table 6-2 are mechanical properties of the H-13 steel alloy from which the track pin casing is fabricated. This high strength tool steel, according to Carpenter Steel Division of CARTECH, was designed particularly for applications requiring extreme toughness. H-13 can be hardened without danger of decarburization in controlled-atmosphere furnaces using a dew point between 40°F and 55°F or from neutral salt baths properly rectified.

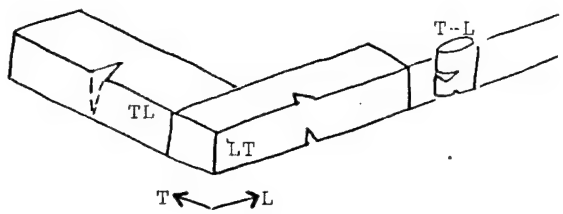
The machinability of H-13 may be rated 45-55 percent of a 1 percent carbon water-hardening tool steel, using high speed cutting tools with turning speeds of 75 to 90 surface feet per minute.

Typical applications, in addition to the present hybrid track pin casings, include forging dies, heavy-duty compression tools, bulldozer dies, and hot-piercing and hot-forming punches. Because of extreme toughness, this material is excellent for cold work applications where other steels have failed.

In Table 6-3, the effect of tempering temperature on H-13 hardness is indicated. It is particularly important that full hardness be maintained through a tempering temperature of 1000°F, the approximate temperature for both insertion assembly and solution heat treat of DWAl 20®. In addition to the above attributes, H-13 tool steel was also chosen because of high

Table 6-1. Notch Toughness Data for DWAl 20® (Reference 4)

DWAl 20® System	Orientation	Heat-treat Condition	Energy Dissipated (Ft.-Lb.) Notched	Unnotched	Kmax. (ksi $\sqrt{\text{in.}}$)
20 v/o SiCp/6061	LT	F	4.47	18.8	20.8
	LT	T6	.80	8.4	22.0
25 v/o SiCp/6061	LT	F	2.41	---	19.7
	LT	T6	.64	---	22.3
	TL	F	2.38	---	18.3
	TL	T6	.61	---	24.1



Orientation Legend

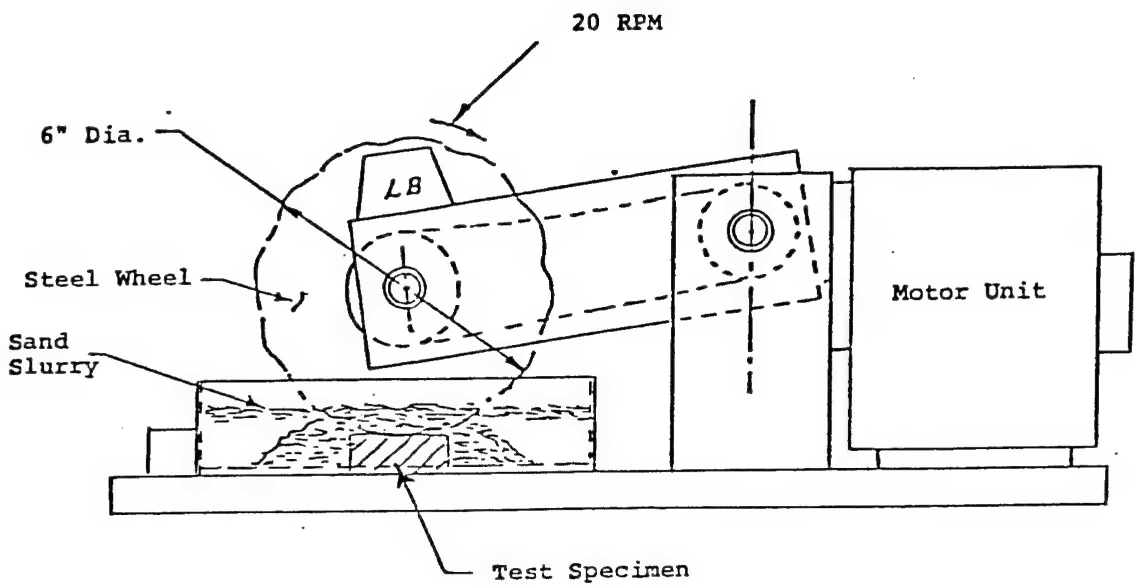


Figure 6-2. Schematic of Test Apparatus for Steel Wheel Abrasion Tests

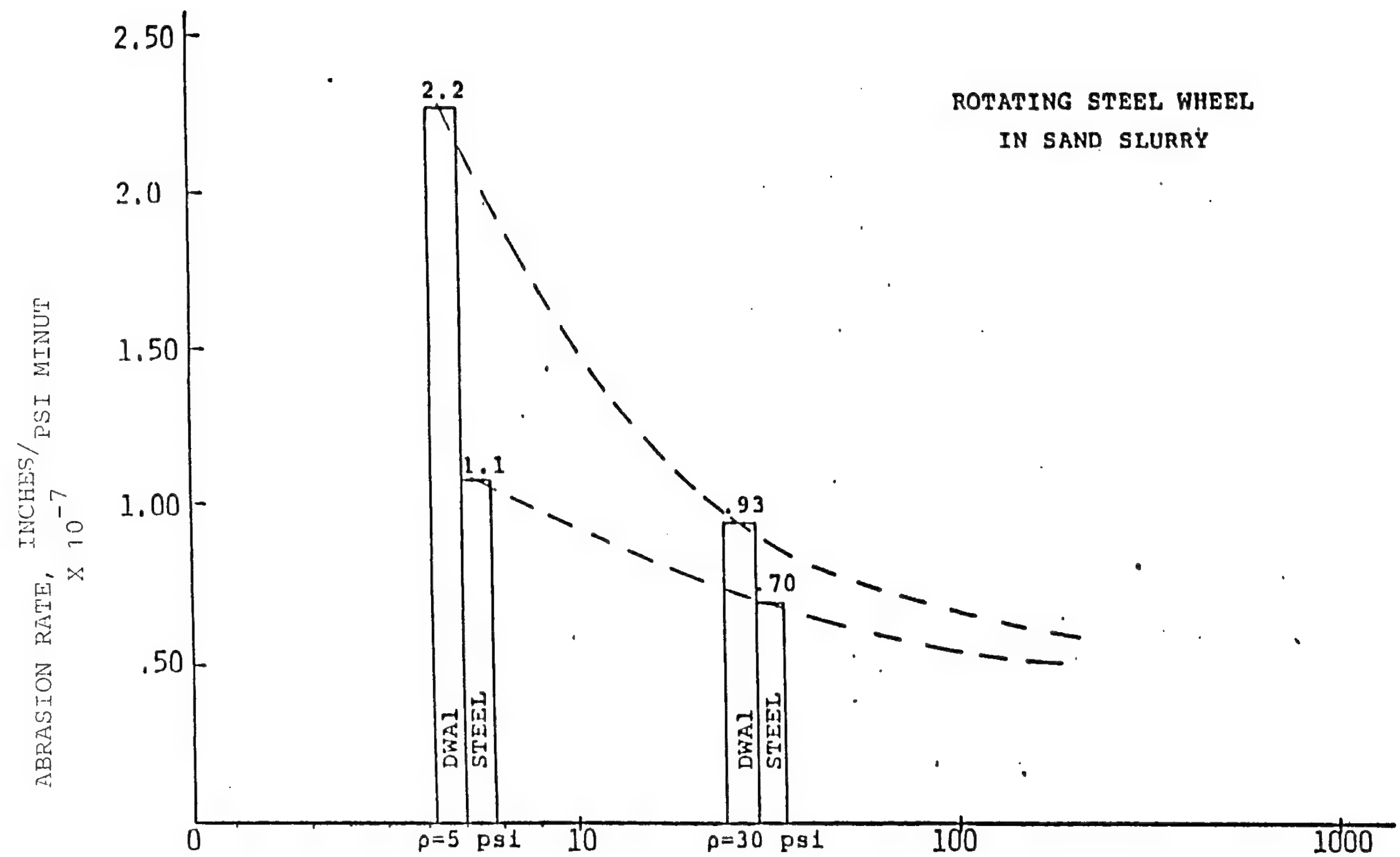


Figure 6-3. Preliminary Results of Material Wear (Cutting Rate) Variation with Steel Wheel Pressure Exerted on Test Specimen, as Function of Specimen Type

Table 6-2. Physical and Mechanical Properties of H-13 Steel

PHYSICAL PROPERTIES:

Specific gravity 7.77
Density
  lb/in^3 .... 0.28
  kg/m^3 7750
Critical temperature A_{c1} .... 1505°F (818°C)
Specific heat
  Btu/lb · °F 0.11
  kJ/kg · K 0.460

Coefficient of Thermal Expansion

Temperature Range °F	Temperature Range °C	10^{-6}/°F	10^{-6}/°C
80- 200	27- 93	6.1	11.0
80- 400	27-204	6.4	11.5
80- 800	27-427	6.8	12.2
80-1000	27-538	6.9	12.4
80-1200	27-649	7.3	13.1
80-1450	27-788	7.5	13.5
500-1200	260-649	7.8	14.0
500-1450	260-688	8.0	14.4
800-1200	427-649	8.1	14.6
800-1450	427-788	8.2	14.8

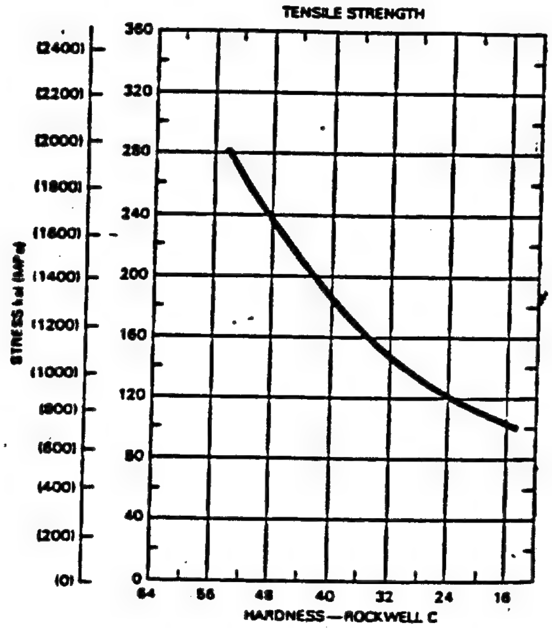
Modulus of Elasticity

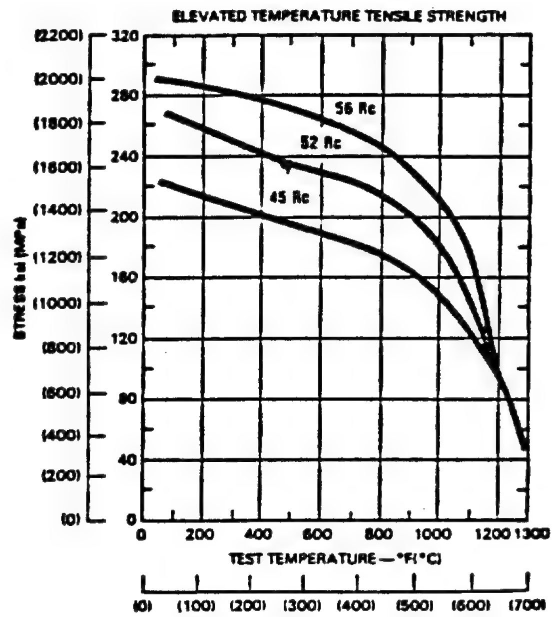
Temperature °F	Temperature °C	psi x 10^6	MPa x 10^3
70	21	30.5	210.3
300	149	27.8	191.7
500	260	26.1	180.0
650	343	27.7	191.0
800	427	27.3	188.2
900	482	27.0	186.2
1000	538	22.7	156.5
1200	649	16.5	113.8

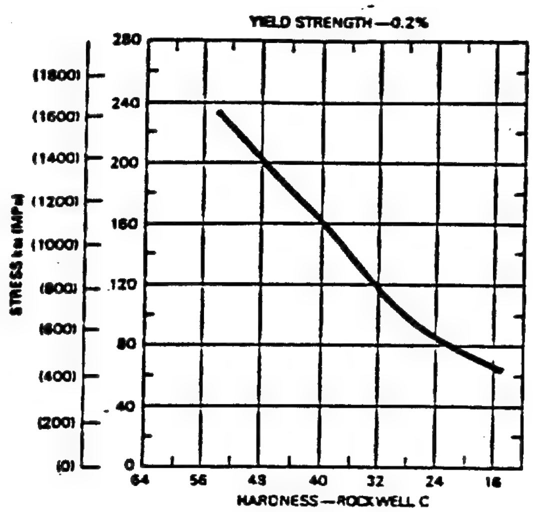
Thermal Conductivity

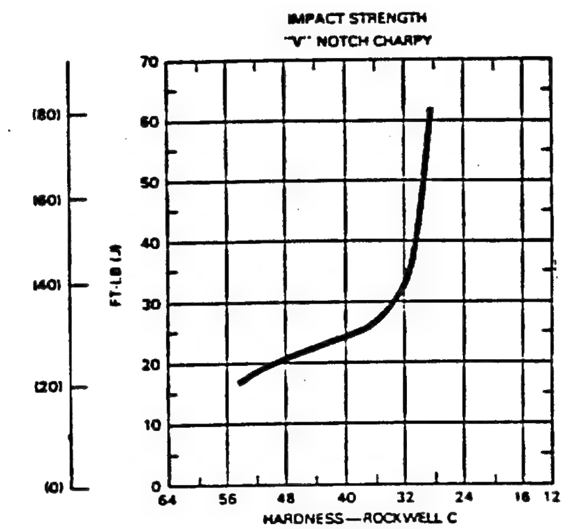
Temperature °F	Temperature °C	Btu-in/ft^2/hr/°F	W/m · K
420	216	198	28.6
660	349	197	28.4
890	477	196	28.3
1120	604	199	28.7

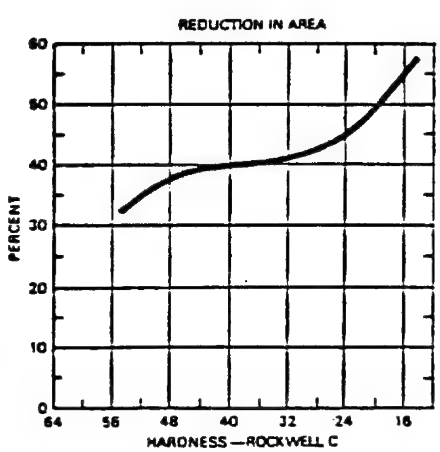
Table 6-2. Physical and Mechanical Properties of H-13 Steel (Cont.)











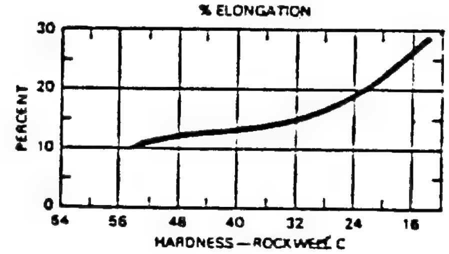


Table 6-3. H-13 Tempering Temperature Versus Rockwell C Hardness

Tempering Temperature °F	Rockwell C Hardness (Air or Oil Quenched)
600	51/53
800	51/53
900	51/53
950	52/54
1000	52/54
1050	51/53
1100	49/51

strength, compatibility of CTE with that of the DWAl sleeves, and availability for this contract. However, H-13 was recognized as questionable for fatigue strength of 150 ksi at $2x10^6$ cycles.

In future evaluations, one of the other candidate steels could prove to be more satisfactory in fatigue; however, with availability as an important criterion, the H-13 steel casing material was chosen for this demonstration.

6.3. Testing

Test operations associated with the hybrid lightweight track pin involved primarily:

- Quality Control,
- Nondestructive Evaluation (NDE),
- Static Testing,
- Fatigue Testing.

In addition, a simplified sleeve press-out investigation was conducted.

Quality control of the steel jacket involved manufacturers' certifications combined with DWA visual, dimensional, and hardness testing. For DWAl 20®, initial extrusion billets quality was gauged by billet densification measurements before extrusion, by tensile test of lot samples of extruded tube after heat treatment, and by metallography. Hardness measurements were used to verify the tensile properties obtained. Dimensions, workmanship, and appearance were observed.

6.3.1. Nondestructive Evaluation (NDE). NDE of the track pins planned for production, is similar to that stated above for quality control, i.e., DWAl 20® billet density and hardness of extruded tubes. In addition, each tube produced will be passed through an optical scanner to verify dimensions, and surface shot peening will be assured by military specification certification. Further recommended for NDE testing of the final track pins are:

- ultrasonic measurement of the axial modulus and flexural natural frequency;
- flex each unit by application of a fixed load; then record (1) stress-strain relationship, (2) microacoustic emission spectrum.

6.3.2. Static Testing. The load-deflection data resulting from static testing of a hybrid, lightweight track pin are shown in Figure 6-4. The application of the required 11,000 pound force resulted in an initial linear load-strain response through 6000 pounds. After the force of 11,000 pounds was applied and removed, a permanent set of 0.030 inch was measured. The test set-up for the specified three-point bend test is illustrated in Figure 6-5, showing the sample pin installed atop two pillow blocks spaced 19 inches apart with a third block (load point) centered above the pin. In

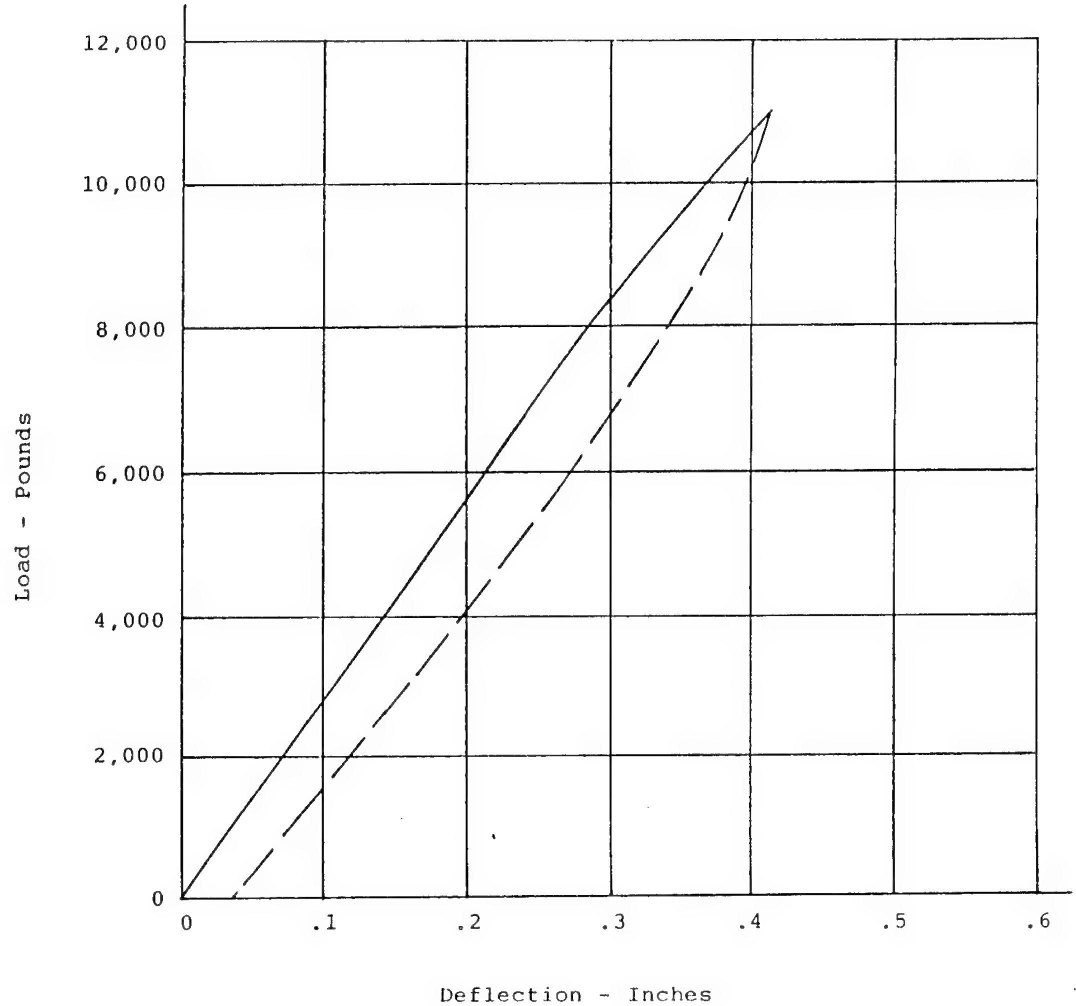


Figure 6-4. Results of Static Testing a Final Hybrid Lightweight Track Pin

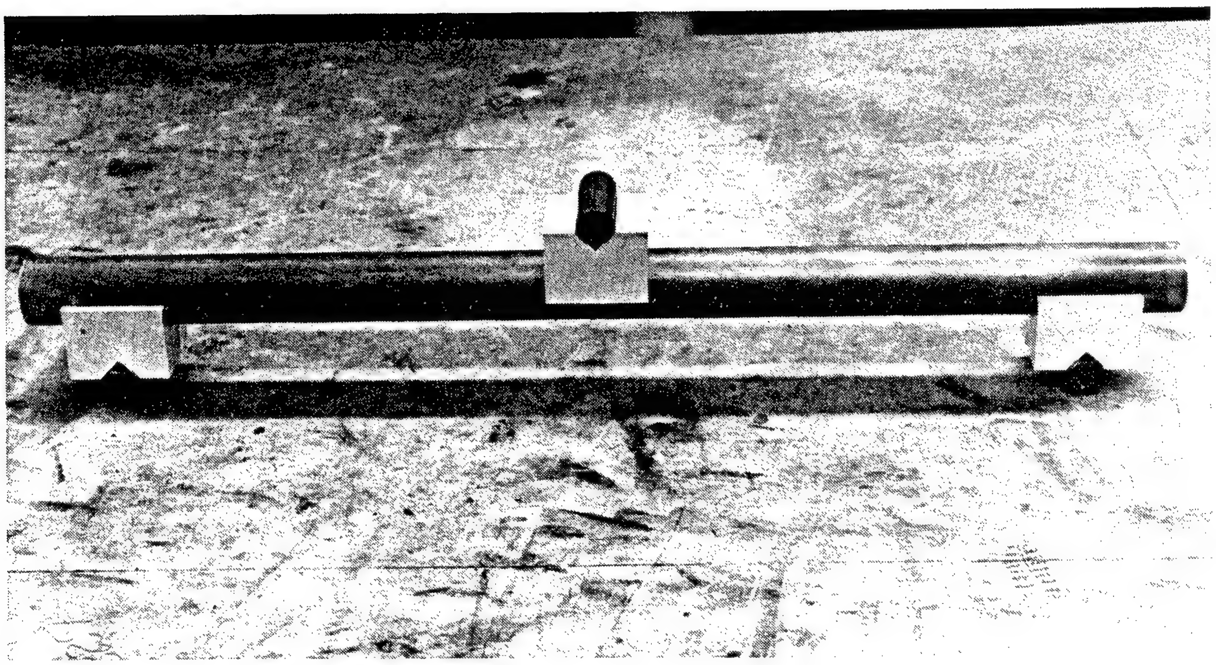


Figure 6-5. Sample Track Pin Installed on Test Pillow Blocks with a Third Pillow Block Centered on Top

Figure 6-6, this test arrangement is shown, including a base bar positioned in a light duty test machine with measurement instrumentation attached. Details of a typical bend test fixture, i.e., pillow block and bearing pin, are depicted in Figure 6-7.

6.3.3. Fatigue Testing. Final hybrid lightweight track pin fatigue testing was conducted by Atlas Testing Laboratory, Los Angeles, California. The test set-up was similar to that used in the static test except that the test fixture was mounted in a Sontag fatigue test machine. A force equivalent to a bend stress of 140 ksi maximum and 1.91 ksi minimum was applied. Two pins were tested to failure with an average of 107,000 fatigue cycles before failure.

An intensive evaluation of the selected track pin materials and design details, as well as the fatigue test equipment and methods, revealed the following options to improve the track pin fatigue performance:

- Select a casing steel that is more compatible with the fatigue requirement.

- Increase the wall thickness of the steel casing at the expense of weight savings.

- Modify the means to achieve the desired heat-treated condition of both pin components.

- Improve the temperature uniformity of the insertion assembly, especially reducing the top end temperature drop off. (This will allow the insertion at a lower maximum temperature.)

A fatigue-tested track pin is presented in Figure 6-8 showing strain gauges to measure and assure the required stress levels. The fracture river pattern leading to a fatigue "thumb nail" is shown clearly in Figure 6-9 at the tension side of the test sample pin. Interestingly, the failure apparently originated at the interface between the DWAl and the steel, rather than on the outside surface of the steel, at the point of maximum tensile stress. This may suggest inadvertent scratching during insertion, a machining flaw, or that a reaction between the DWAl sleeve and the steel casing took place.

7.0. TRACK PIN PRODUCTION ECONOMIC ANALYSIS

This hybrid lightweight track pin economic analysis is based on the following criteria, for a production rate of 500,000 track pins per year:

- All costs expressed in current fiscal year (FY85) dollars;

- All cost estimates, where applicable, based on the one shift, eight hour day, five day week;

- All R&D costs considered spent (expended to assure experience to the producer).

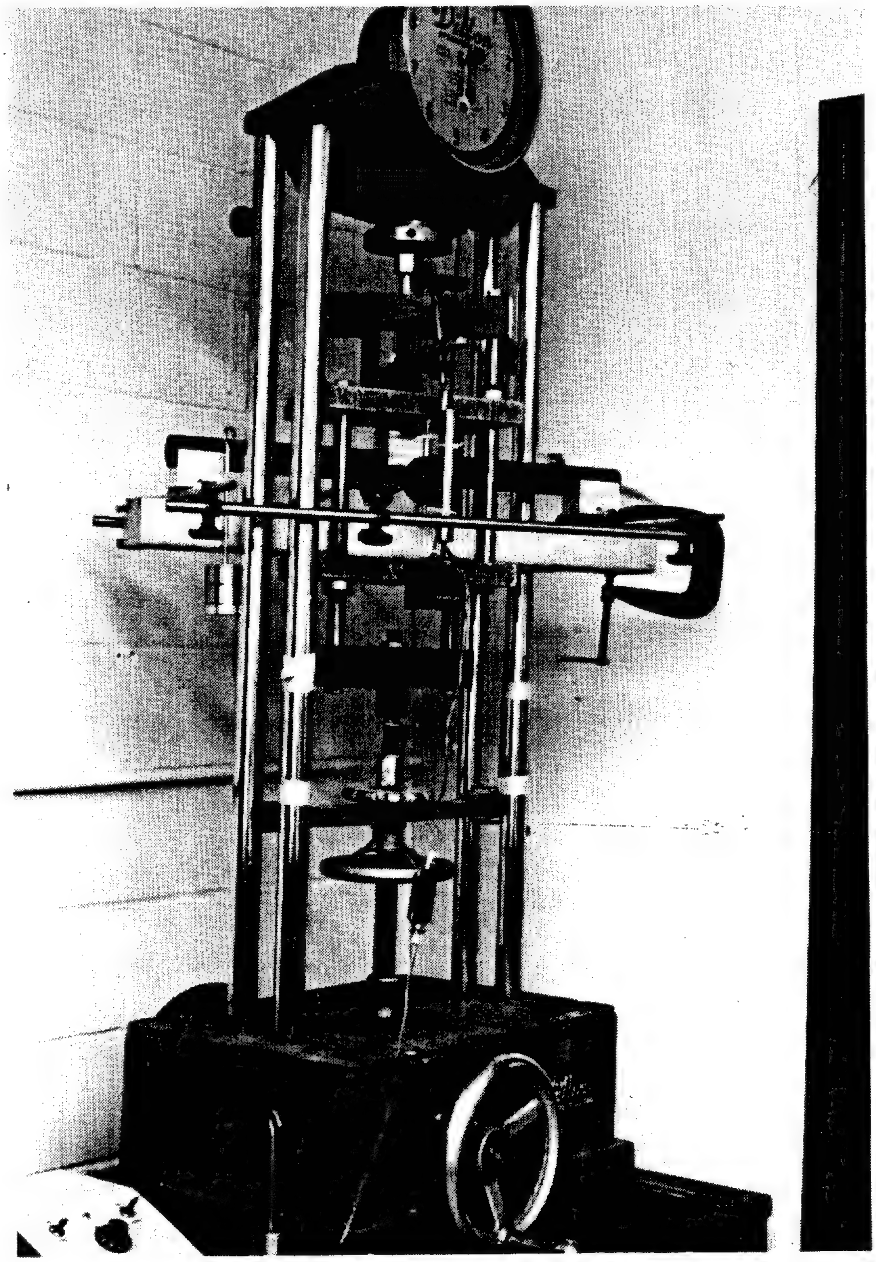
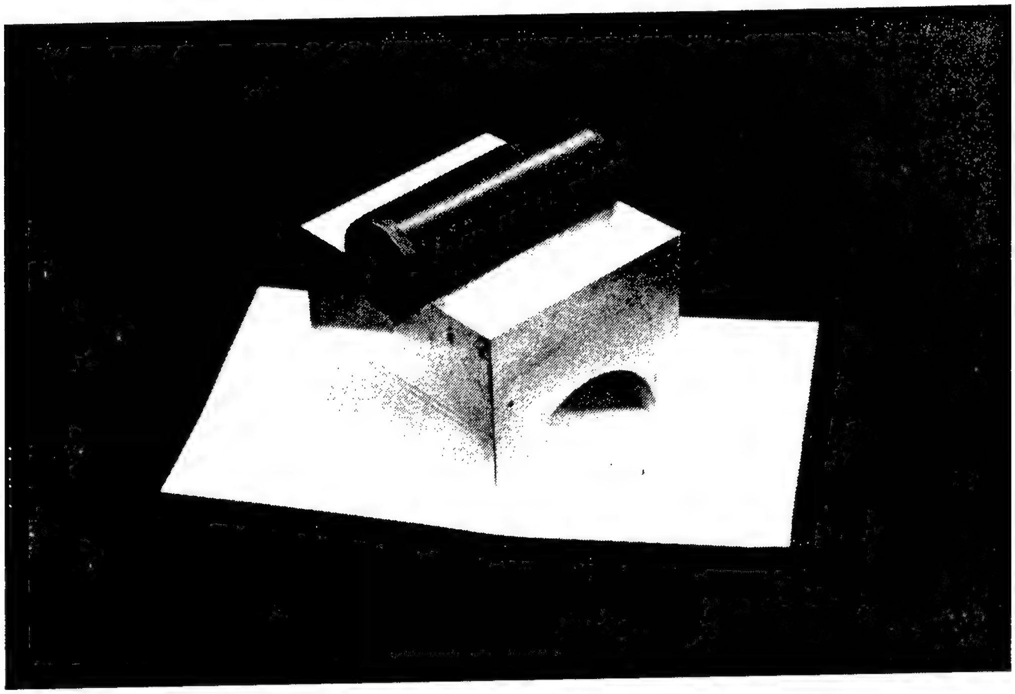
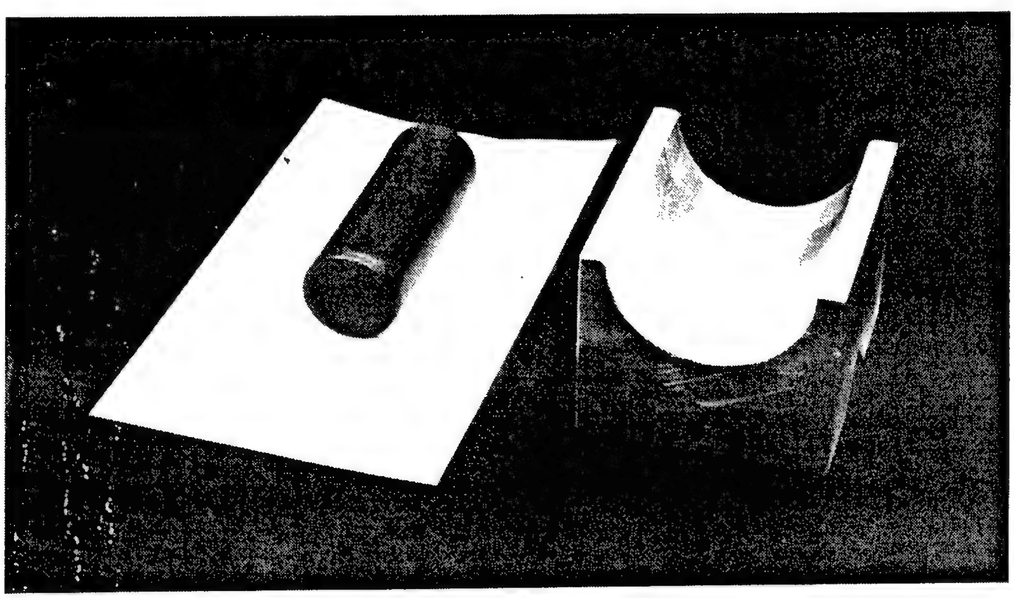


Figure 6-6. Sample Track Pin Arrangement in the DWA Test Machine, Instrumentation Attached



A. Assembled Bend Test Pillow Block



B. Dis-Assembled Bend Test Pillow Block

Figure 6-7. Typical Bend Test Fixture for DWAl 20® and Steel Track Pin

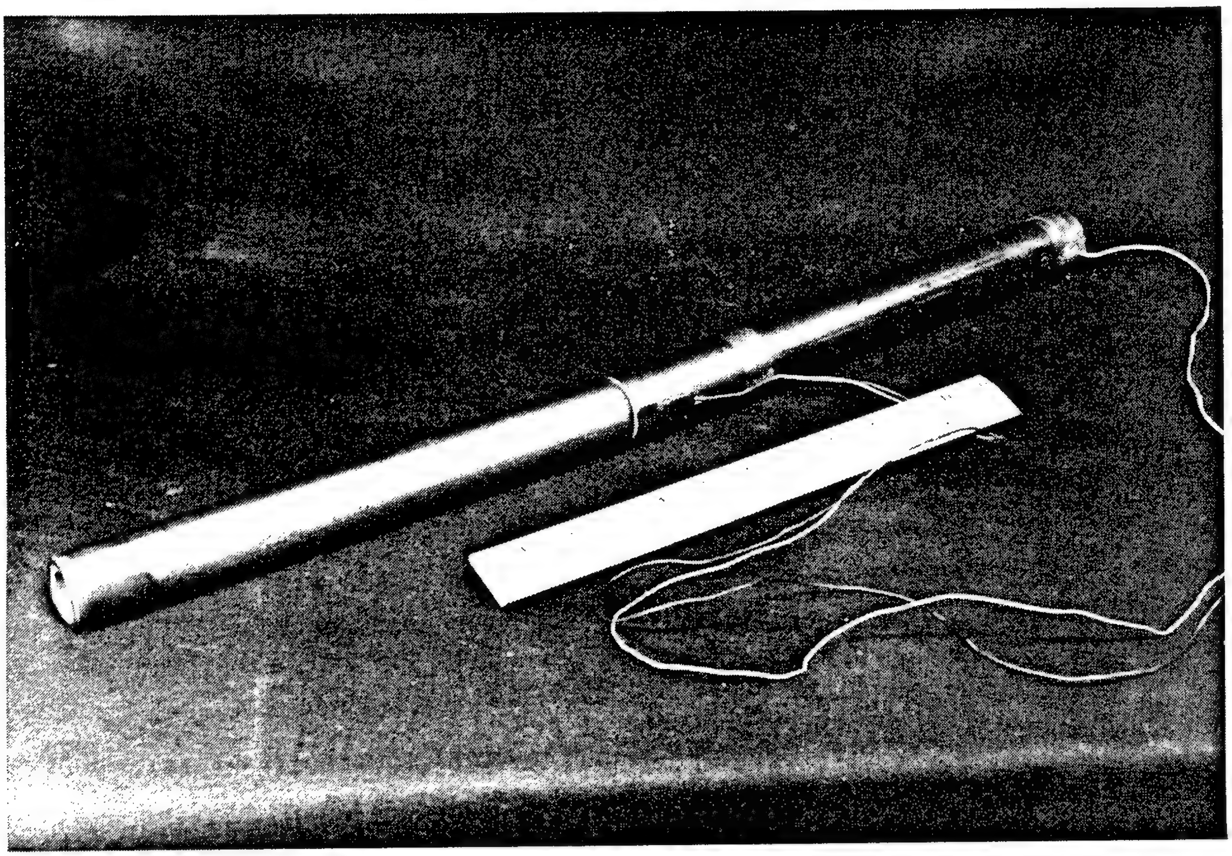


Figure 6-8. Post-Test Photograph of Instrumented Fatigue Test Track Pin

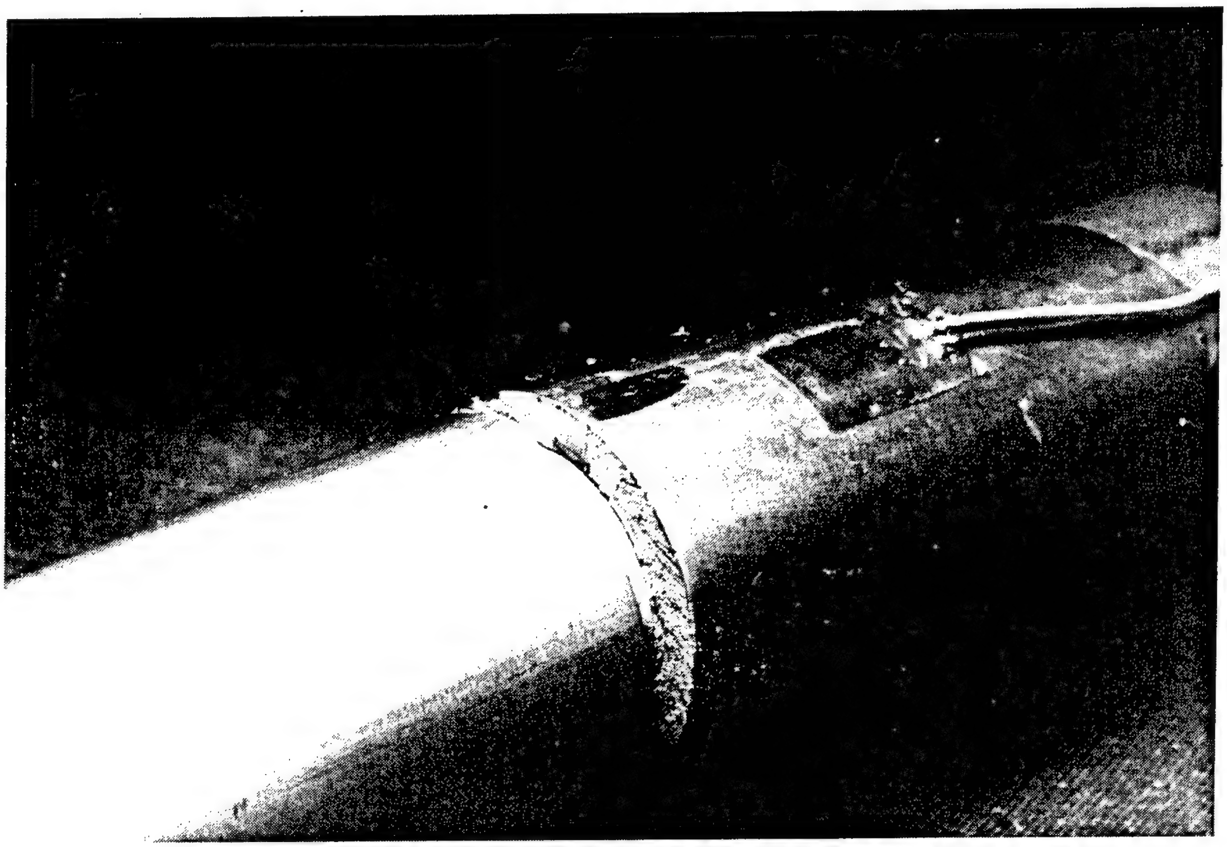


Figure 6-9. Post-test Photograph of the Fatigue Fracture in the Test Sample Track Pin. (Note: Fracture Origin at Inside Surface of Steel)

7.1. Nonrecurring Investment

This cost element includes engineering and capitalization to achieve initial total production capability for the hybrid lightweight track pin implementation on the M1 MBT, including:

• Engineering Support	$200,000
• Plant Facilities	$400,000
• Pin Insertion Assembly Apparatus	$200,000
• Test Equipment	$200,000
Sub-total	$1,000,000

7.2. Production

This cost element includes manufacturing costs associated with producing the lightweight track pins for the M1 MBT, including DWAl sleeve fabrication and preparation for insertion, insertion assembly operations, heat treatment, post-insertion final machining, and quality control.

These production costs were estimated by the following procedure:

- Determined number, characteristics, and cost of billets required for extrusion of the specified number of pin lengths (DWAl and steel);
- Calculated cost to extrude the billets;
- Calculated cost for DWA to assemble the required number of track pins;
- Allocated engineering support to conduct the track pin production program.

7.2.1. DWAl 20® Sleeve Production. The DWAl 20® sleeve production extrusion cost was estimated by RMI, Ashtabule, Ohio, based on 1 inch O.D. x 0.080 inch wall thickness x 28 inch length. Each billet must be 5.1 inch O.D. with a hole drilled through with 0.95 inch I.D., and 10 inch length, chamfered on one end. Each billet provides 20 of the 28 inch long sleeves so that 10^6 feet provides 428,640 sleeves derived from 21,432 billets. The cost to produce the rough pin sleeves is shown in Table 7-1 for 250,000 feet through 10^6 feet. The cost to produce 500,000 track pin sleeves was extrapolated to be $5,770,000.

7.2.2. Steel Casing Production. The steel casing production extrusion cost was estimated by RMI and Carpenter Steel Division of Carpenter Technology Corp., Reading, Pennsylvania. Steel casing cost estimates were based on steel billets purchased by RMI from Carpenter. Each steel billet had to be 5.95 inches O.D. with a hole drilled with 1.125 inch I.D. and 19-1/2 inches in length, chamfered on one end. Each billet had to provide 20 of the 28 inch long casings for 10^6 feet to provide 428,640 casings derived

Table 7-1. Schedule of DWAl 20® Sleeve Production Cost

DWAl 20® Sleeve Extrusion Cost

Billets Required	Number of Linear Ft.	Number of Sleeves	$/Billet	$/Sleeve	Total $
21,432	10^6	428,640	230	11.485	4,929,360
16,074	750 K	321,480	240	11.980	3,857,760
10,716	500 K	214,320	250	12.484	2,679,000
5,358	250 K	107,160	260	12.984	1,393,080

from 21,432 billets. The cost to produce the rough pin casings is shown in Table 7-2 for 250,000 feet through 10^6 feet, including the cost of the steel. The cost to produce 500,000 track pin casings was extrapolated to be $11,470,000.

Larger billets and more efficient extrusion operations could result in additional cost savings up to possibly 30 percent.

7.2.3. DWAl 20® Billet Fabrication. The cost to fabricate DWAl 20® (e.g., 25v/o SiCp/6061) was estimated to be $12 per pound at the quantity level of 1,000,000 pounds. Using this as the cost datum, the learning curve presented in Figure 7-1 was constructed. At $12 per pound, one DWAl billet of specified extrusion diameter and length costs $275. At the same production level, cleanup machining and drilling increases the cost of extrusion-ready billets to $450 per billet. Based on the above estimates, 500,000 track pins would cost $12,500,000 as indicated on Figure 7-1.

7.2.4. Pin Insertion Assembly. Before insertion assembly can commence, the DWAl sleeves and steel casings, as-extruded, must be prepared for interference fit, including the following operations (costs shown are for 20 pins):

• Heat-treat and straighten casings		$200.00
• Heat-treat and straighten sleeves		$100.00
• Trim casings to insertion length		$ 30.00
• Centerless-grind casings as required		$100.00
• Hone casings as required		$ 80.00
• Trim sleeves to insertion length		$ 30.00
• Centerless-grind sleeves as required		$100.00
• Prepare one end of casing to accept DWAl insertion		$ 50.00
• Prepare one end of sleeve to insert into casing		$ 30.00
(20 pins)	Sub-total	$720.00

From Reference 6, the preparation for producing 500,000 pins is $7,500,000.

The cost of pin insertion operations to produce 500,000 track pins per calendar year was estimated based on the following assumptions:

- A quantity of 22 insertion devices, minimum.
- DWAl billet production capacity of a minimum of 25,000 billets per year (about 13 billets per hour under standard conditions).

For this estimate, a work shift of six persons would be required to load and check alignment, insert the sleeves into the casings, remove the

Table 7-2. Schedule of High Strength Steel Casing Production Cost, Including Billets

DWA1 20 Sleeve Extrusion Cost

Billets Required	Number of Linear Ft.	Number of Casings	$/Billet	$/ Casing	Total $
21,432	10^6	428,640	473	23.62	10,137,336
16,074	750 K	321,480	482.50	24.094	7,755,705
10,716	500 K	214,320	492	24.568	5,272,272
5,358	250 K	107,160	502	25.07	2,698,716

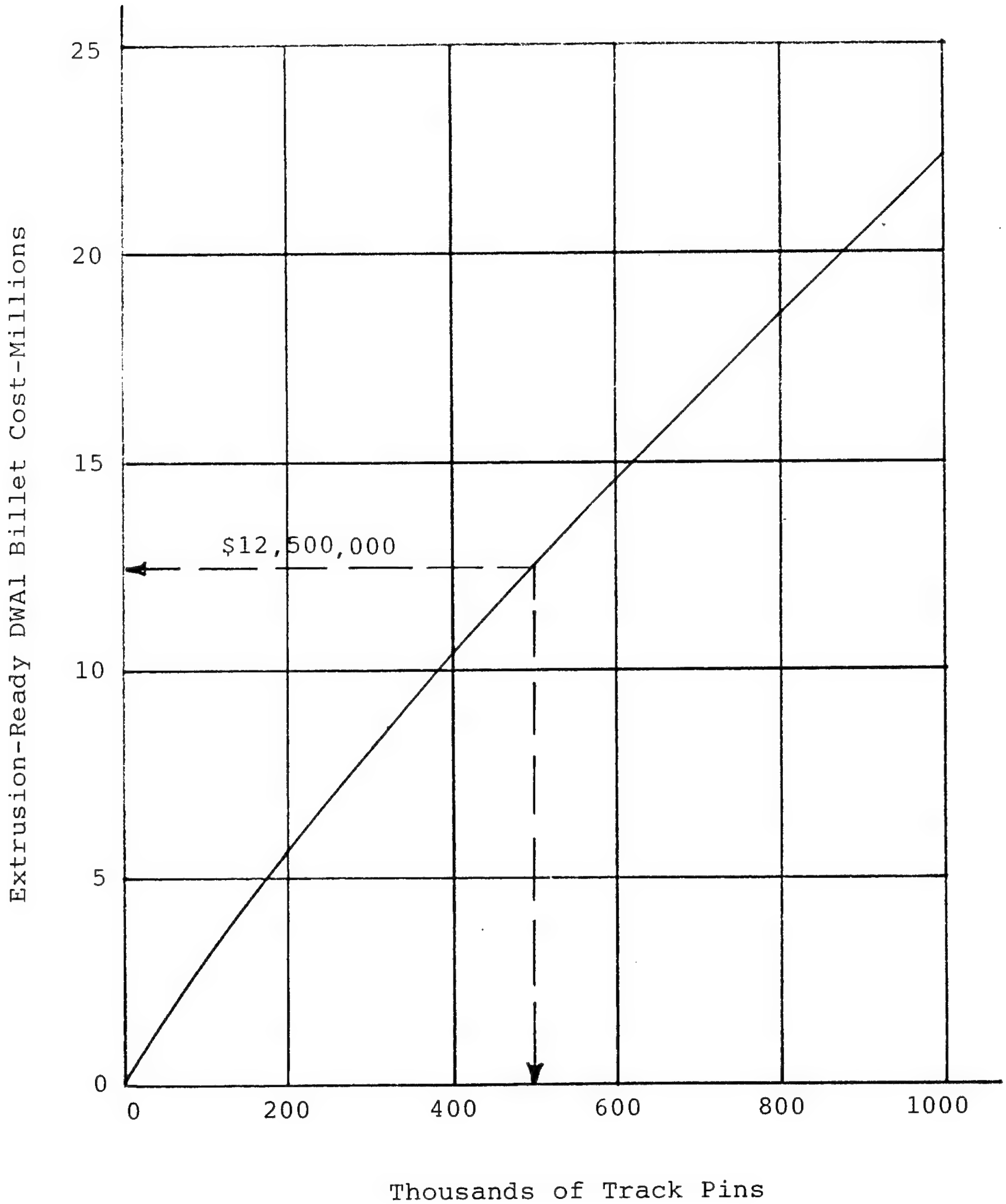


Figure 7-1. Cost of DWAl 20® Billets Required for Production of the Hybrid Lightweight MBT Track Pin

assembled pins, and prepare for the final machining. Assuming 2,000 productive hours per year and a technician's pay rate of $28 per hour including overhead and fee, the cost of insertion for 500,000 track pins is calculated by:

2,000 hrs x $28/hr-Tech x 6 Tech = $336,000

Adding the costs of preparation and pin insertion:

$ 336,000	Insertion Assembly
$7,500,000	Preparation
$7,836,000 for 500,000 pins.	

7.2.5. Post Insertion Operations (P.I.O.). Subsequent to insertion and assembly of the hybrid track pins, the following post insertion operations are required annually for 500,000 track pins:

• Machine each pin to precision-bevelled length (approximately $3.00 per pin)	$1,500,000
• Grind the contoured configuration on each pin end per TACOM drawing 12274418	$3,000,000
• Shot peen outer surface of each pin per Military Standard MIL-S-13165.	$1,000,000
TOTAL COST FOR P.I.O.	$5,500,000

7.2.6. Recurring Engineering. The following assumptions formed the basis for estimating the recurring engineering cost in support of hybrid track pin production:

- 2,000 productive hours per year.
- One engineer full time to:
  - coordinate production in-house;
  - coordinate work conducted outside;
  - perform system engineering.
- Other engineering:
  - Maintenance, 10 percent = 200 hrs.
  - Value, 10 percent = 200 hrs.
  - Reliability, 20 percent = 400 hrs.

Calculating the recurring engineering cost, based on an average overall rate of approximately $56 per hour:

2,000 (1.4) x $56 per hour = $1,568,000

7.2.7. Sustaining Tooling. This cost element involves maintenance, replacement and/or modification of the pin insertion assembly apparatus and all associated tools subject to wear-out or breakdown. This cost is assumed to be 10 percent of the following previously estimated costs:

- Pin Insertion Assembly Apparatus
- Test Equipment

The sum of the above two items is \$400,000; so that sustaining tooling cost is:

$$0.1 \times \$400,000 = \$40,000.$$

7.2.8. Quality Control. This cost element includes the cost of implementing the controls necessary to insure that the manufacturing process produces a component which meets the prescribed standards. It includes the cost of receiving and final inspecting the tools, parts, and subassemblies, and includes such tasks as reliability testing and establishing statistical methods for determining the performance of manufacturing processes.

For the hybrid track pin production program, this cost was estimated by assuming the requirement for one full-time engineer plus 15 percent of the cost of pin insertion assembly (\$50,400).

Calculating the estimated quality control cost;

One Engineer = 2,000 x \$56 per hour	=	\$112,000
.15 x \$336,000	=	\$ 50,400
		\$162,400

7.2.9. Other Production Costs. This cost element involves the following expenditures:

- liaison travel expenses between DWA and the major subcontractors associated with track pin production;
- cost of outside testing, including sample structural testing and Non-destructive Evaluation (NDE) not performed by DWA;
- shipping costs, from subcontractors to DWA and from DWA to TACOM.

7.2.9.1. Travel. This cost is based on four trips per year to RMI, Ashtabula, Ohio, for five days each trip:

- Air Fare (round trip)--------------------\$ 700
- Per Diem---------------------------------\$ 250
- Lodging----------------------------------\$ 240
- Mileage----------------------------------\$ 145

\$1,335

x 4 = \$5,340 (approx. \$6,000)

7.2.9.2. Production Testing. Production testing consists of receiving inspection tests, density measurement of DWAl 20® billets, and fatigue

testing of random samples of the end items. Receiving inspection includes the powdered aluminum matrix and the particulate reinforcement as well as post-fabricated component elements; i.e., the steel casing tubes and the DWAl sleeve tubes. All of the above, except for the random fatigue testing, have been priced previously in this report.

To estimate the cost of random sampling for fatigue testing, the operations at Atlas Testing Laboratory, Los Angeles, California, were used for guidance. For high quantity testing, the cost per test was estimated to be approximately $200 per test. This cost assumed three-point bending, 150 ksi stress with force applied at the center of the supports spread 19 inches apart. Further assumed was an average sampling rate (Reference 7) of one track pin per 100 pins fabricated. Cost for this operation was then calculated for 500,000 pins annually by: 500,000/100 x $200/test = $1,000,000 total, annually.

7.2.9.3. Shipping costs. This cost element includes batch shipping expenses incurred by subcontractors and by DWA, as follows (annually):

• Shipping DWAl billet to Extrusion plant for extrusion	$ 50,000
• Shipping track pin components from Extrusion Plant to DWA for heat treatment	$250,000
• Shipping components after heat treatment to machine shop for trimming	$100,000
• Shipping casings from machine shop to centerless grinder	$ 50,000
• Shipping casings from centerless grinder to I.D. honing company	$ 50,000
• Shipping casings from I.D. honing company to DWA	$ 50,000
• Shipping sleeves from machine shop to centerless grinder	$ 50,000
• Shipping sleeves from centerless grinder to DWA	$ 50,000
• Shipping assembled track pins from DWA to machine shop for end machining before grinding contours	$100,000
• Shipping track pins from machine shop to grinding company for end contours	$100,000
• Shipping track pins from grinding company to shot peening company	$100,000
• Shipping randomly selected track pins from shot peening company to fatigue test laboratory	$ 1,000

- Shipping nontested track pins from shot peening company to DWA $99,000

- Shipping tested track pins from testing laboratory to DWA $1,000

- Shipping production end items from DWA to TACOM $250,000

TOTAL SHIPPING COSTS	$1,050,000

Due to the magnitude of the shipping cost estimate, a trade-off analysis was conducted to compare the cost of expanding DWA facilities to accomplish most of the operations involving shipping, against relying on services outside of DWA. Accordingly, a facilities expansion cost was estimated to be approximately $1,000,000 while the affected annual shipping cost was $750,000. The enlarged facilities would incur costs to hire and train personnel in skills new to DWA; however, the outside services approach would recur for each 500,000 annual pin buy. A more detailed evaluation of these options should be considered in the future. In the meantime, using outside support was assumed in the present production economic analysis.

7.3. Total Production Cost

The total annual production cost estimate is for the quantity of 500,000 track pins, summarized as follows:

Nonrecurring Investment	$ 1,000,000
DWAl 20® Sleeve Tube Extrusion	$ 5,770,000
Steel Casing Tube Extrusion	$11,470,000
DWAl 20® Billet Fabrication	$12,500,000
Pin Insertion Assembly	$ 7,836,000
Post Insertion Operations	$ 5,500,000
Recurring Engineering	$ 1,568,000
Sustaining Tooling	$ 40,000
Quality Control	$ 162,000
Travel	$ 6,000
Production Testing	$ 1,000,000
Shipping	$ 1,050,000
	$47,902,000

7.4. Production Cost Estimate Reduction

The foregoing economic analysis was conducted almost solely on the basis of activities experienced during the hybrid pin development and demonstration program. Consequently, some of the more expensive operations were re-evaluated to assess the likelihood of a lower cost per track pin. Candidate activites included DWAl 20® billet fabrication, preparation for and extrusion of steel and DWAl tubing, pin insertion assembly, and post insertion operations. These candidates constitute $43,076M of the $47,902M estimated, or about 90 percent of the unrefined total.

A closer look at DWAl billet fabrication and pre-extrusion preparation of the billets indicates that by increasing the billet size, streamlining the billet fabrication process to be more "production oriented," and improving the methods of machining required before extrusion, may combine with lower raw material costs for quantity procurement to yield as much as a 40 percent reduction in DWAl 20® billet fabrication: $12,500,000 x 0.6 = $7,500,000.

The DWAl 20® sleeve tube extrusion also benefits from larger billets and by accelerating production at the extrusion plant. This cost reduction could reach 20 percent: $5,770,000 x 0.8 = $4,616,000

Steel casing tube extrusion could be reduced by a lower steel billet cost for quantity procurement, by competitive purchasing, and by accelerating production at the extrusion plant. The reduction in cost could be as much 15 percent: $11,470,000 x 0.85 = $9,749,500

Through efficient operational innovations and improvements in tools and production practices, it is estimated that both the pin insertion assembly and post insertion operations could be reduced in cost by 15 percent:

$7,836,000 x 0.85 = $ 6,660,600
$5,500,000 x 0.85 = $ 4,675,000

Estimated New Cost = $11,335,600

Due to the above improvements in production operations, the accompanying requirement for recurring engineering could be expected to drop 15 percent:

$1,568,000 x 0.85 = $ 1,332,800

By applying the above adjustments to the total estimated annual cost for 500,000 track pins, the previous estimate of $57,902,000 is reduced to $37,791.300. Thus, the cost per track pin is lowered from $96 per pin to $75 per pin ($27,900 per tank set).

LIST OF REFERENCES

1 Raytheon Interim Report, Phase II, NSWC Contract N60921-82-C-A147, August 1984.

2 DWA Final Report, Phase II-F DARPA Contract N00024-80-C-5637, March 1983 (DWA Job 600).

3 DWA presentation to U.S. Army, Contract DAAG46-82-C-0031 (DWA Job 749).

4 DWA Final Report, NSWC Contract N60921-83-C-0004, July 1983 (DWA Job 826).

5 DWA Final Report, NSRDC Contract N00167-81-C-0059 (DWA Job 654).

6 Rimo Book, call Larry or Robert Riley.

7 MIL-STD-105D, "Sampling Procedures and Tables for Inspection by Attributes.

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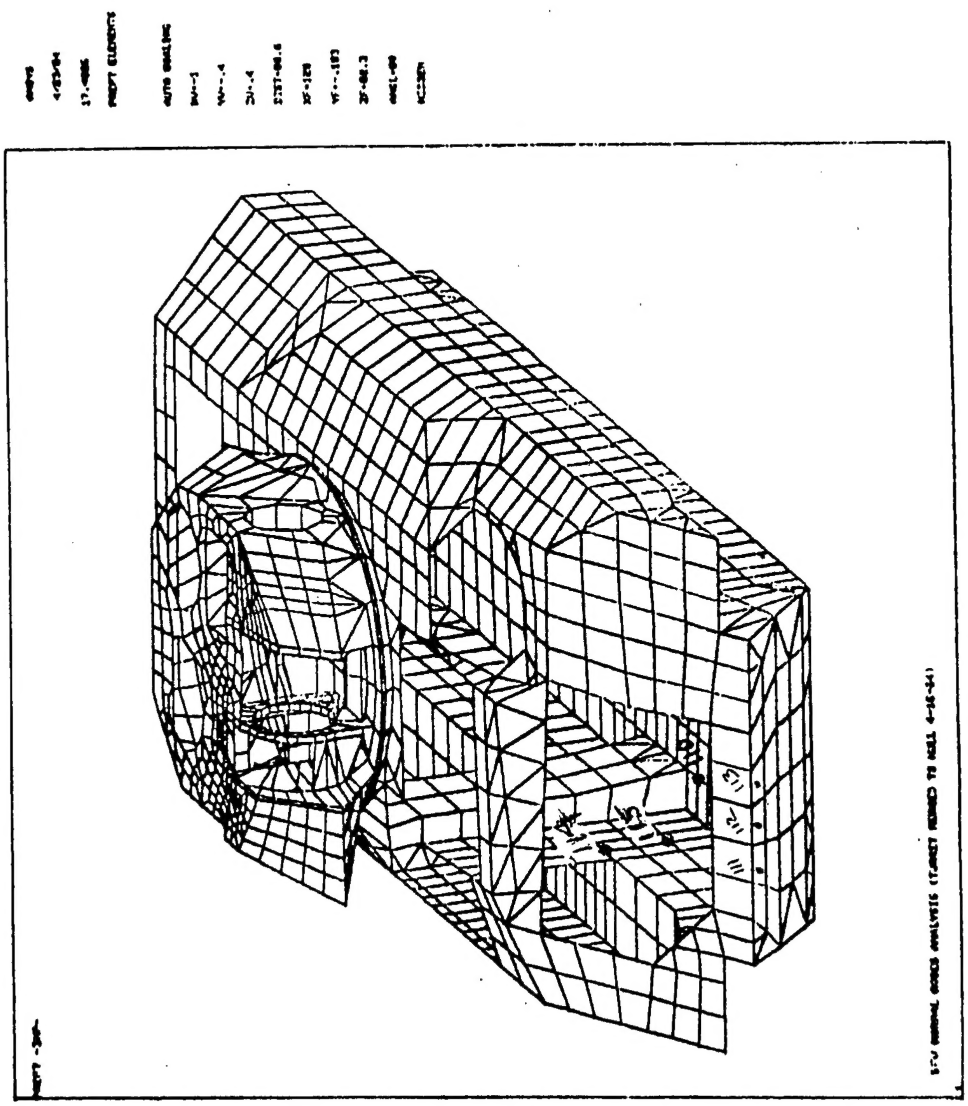

Figure 9.